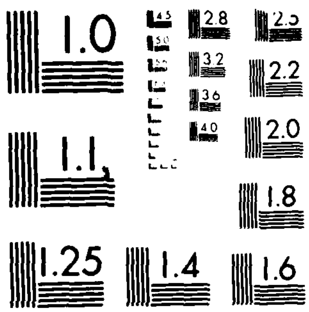
AD-A142 548 A SYNOPTIC CASE STUDY ANALYSIS OF THE OCEAN TEMPERATURE 1/1
ANOMALIES IN THE..(U) NAVAL POSTGRADUATE SCHOOL
MONTEREY CA R L ELSBERRY JAN 84 NPS63-84-003

UNCLASSIFIED F/G 8/10 NL

END
DATE
FILMED
8-84
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NPS-63-84-003

AD-A142 548

NAVAL POSTGRADUATE SCHOOL

Monterey, California

DTIC
ELECTE
JUN 2 7 1984
S D
A

A SYNOPTIC CASE STUDY ANALYSIS OF THE OCEAN TEMPERATURE ANOMALIES IN THE CENTRAL PACIFIC REGION DURING 1976-79

Russell L. Elsberry

January 1984

Final Report for Period October 1982 - September 1983

DTIC FILE COPY

Approved for public release; distribution unlimited.

Prepared for: Naval Ocean Research and Development Activity (Code 320)
NSTL Station, Mississippi 39529

84 06 27 106

NAVAL POSTGRADUATE SCHOOL
Monterey, California 93943

Commodore R. H. Shumaker
Superintendent

David A. Schrady
Provost

The work reported herein is a result of the research project "Modeling Upper Ocean Thermal Structure" supported by the Naval Ocean Research and Development Activity, NSTL Station, MS under Program Element 62759N.

Reproduction of all or part of this report is authorized.

This report was prepared by:

Russell L. Elsberry
Russell L. Elsberry
Professor of Meteorology

Reviewed by:

Robert J. Renard
Robert J. Renard, Chairman
Department of Meteorology

Released by:

J. N. Dyer
John N. Dyer
Dean of Science and Engineering

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NPS-63-84-003	2. GOVT ACCESSION NO. AD-A142548	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A Synoptic Case Study Analysis of the Ocean Temperature Anomalies in the Central Pacific Region during 1976-79		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Russell L. Elsberry		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62795N N6846282WR20098
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Ocean Research and Development Activity NSTL Station, Mississippi 39529		12. REPORT DATE January 1984
		13. NUMBER OF PAGES 75
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ocean temperature anomalies
Ocean temperature prediction
North Pacific Ocean Experiment (NORPAX)
Synoptic ocean analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An attempt is made to trace the history of each significant ocean temperature anomaly found in the North Pacific Experiment TRANSPAC monthly analyses during 1976-79. The prime generation regions are around 170E and 145W and there is a secondary maximum near 170W. The anomalies may reach maximum amplitude at any time between the first month and the last month they are detected. Warm and cold anomalies form during all seasons, and may persist for periods of up to a year. The TRANSPAC data set provides a variety of cases that are suitable for testing ocean prediction models. Selected cases of warm and cold anomalies

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

Unclassified

 SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

are described in some detail and a complete listing of the anomalies is provided in the Appendices.

Abstract

An attempt is made to trace the history of each significant ocean temperature anomaly found in the North Pacific Experiment TRANSPAC monthly analyses during 1976-79. The prime generation regions are around 170E and 145W and there is a secondary maximum near 170W. The anomalies may reach maximum amplitude at any time between the first month and the last month they are detected. Warm and cold anomalies form during all seasons, and may persist for periods of up to a year. The TRANSPAC data set provides a variety of cases that are suitable for testing ocean prediction models. Selected cases of warm and cold anomalies are described in some detail and a complete listing of the anomalies is provided in the Appendices.

DTIC
COPY
INSPECTED
2

A-1

List of Figures

Fig. 18. Similar to Figs. 15-17, except during August 1979.

Fig. 19. Temperature anomaly at 60 m during (a) September, (b) October and (c) November 1977. The corresponding surface temperature anomaly is shown in Fig. 12.

1. Introduction

One of the objectives of the North Pacific Experiment (NORPAX) was to understand the mechanisms that produce persistent ocean temperature anomalies on space scales of 1000's of km. One of the observational components of NORPAX was a ship-of-opportunity program called TRANSPAC (White and Bernstein, 1979). This program led to a series of monthly temperature analyses at various depths over the central Pacific region. The TRANSPAC analyses represent a unique description of the upper ocean thermal structure changes over an extended period. In particular, the analyses may provide the initial and verifying temperature profiles that are required to validate ocean prediction models (Elsberry and Garwood, 1981).

In this study, we examine the development, maintenance and elimination of temperature anomalies between January 1976 and December 1979. An attempt is made to trace the history of each significant anomaly that occurred during these four years. The purpose of this case study approach is to prepare a summary of significant features that ocean prediction models might be expected to forecast. That is, such models will provide an improvement over specification of climatological profiles only if the models are capable of predicting the departures from these climatological conditions.

After briefly describing in the next section the data sources/analyses that are used to form the anomaly fields, a summary of the significant anomalies during the period is given in Section 3. Some particularly interesting examples of cold and warm anomalies are described in Sections 4 and 5. Cases of enhancement and organization of the sub-mixed layer anomalies during the fall and the spring are presented in Section 6. Some cases in which subsurface anomalies were revealed by the removal of a surface layer are treated in Section 7. More detailed descriptions of each anomaly are provided in the Appendix to aid in the comparisons with ocean model predictions.

2. Data

The TRANSPAC data sources and analysis procedures have been described by White and Bernstein (1979). In this study, we use temperature analyses over a domain bounded by 30 N, 50 N, 130 W and 160 E. The grid resolution is 2 deg lat by 5 deg long. Because observations are taken by ships-of-opportunity personnel, the data coverage varies as the shipping tracks between Japan and the United States change with season. During the summer, the ship tracks extend farther north and the data coverage over the domain is good. However, the northern part of the domain is not well sampled during the winter. The original analysis algorithm provided a value at every grid point. Beginning in 1979, the algorithm was changed to exclude a grid point from the analysis if there were less than four observations during the month in the region of that grid point. It becomes clear then that the northwest and southwest corners of the grid are not well sampled and these areas are excluded in the following analyses for all four years. Where minor gaps in the 1979 data appear on the edge or in the interior of the grid, time and space interpolations were made to assure a continuous record. This interpolation was done only at the following levels: 0, 60, 120, 200 and 300 m. As data gaps were not removed in the analyses at the other analysis levels, only the analyses at the indicated levels will be used.

As the approach in this study is to trace the evolution of temperature anomalies during 1976-79, it is important to consider what mean field is to be subtracted to form the anomaly field. Long-term averages of temperature profiles have been calculated by several groups, including NORPAX (Barnett and Ott, 1976). The long-term average temperature for a given month is generally based on all profiles within a latitude-longitude box, and thus does not take into account the location of the profiles relative to the center of the box.

By contrast, the objective analysis technique of White and Bernstein (1979) accounts for the data distribution and spreads the information to adjacent grid points according to a spatial correlation function. Consequently, these analyses are not necessarily consistent with the long-term mean temperature fields. For this reason, the monthly mean temperature field is based on the average over the four years (1976-79). More stable mean temperature fields will be obtained as more years are added to the TRANSPAC sample. The advantage of the four-year mean is that the analysis method is consistent in both the mean and anomaly (deviations from the mean) fields. The disadvantage is that the anomaly fields will differ from other published NORPAX anomaly fields. In particular, two of the four winter periods included extreme conditions in the central Pacific (White and Bernstein, 1979; White, et al., 1980; Haney, 1980; Elsberry, Gallacher and Garwood, 1979). The cold anomalies during these winters thus have a smaller magnitude in this study than in the NORPAX fields.

The four-year mean fields at surface were compared with the long-term mean fields of Barnett and Ott (1976) at each 2 deg lat along 145, 155, 165 and 175 W. It should be emphasized that both of these surface temperature fields are based only on complete vertical temperature profiles, and do not include merchant ship or other surface temperature observations. Many of the 2 deg lat by 10 deg long boxes in the Barnett and Ott (1976) study have fewer than 20 observations; thus, these long-term mean fields may not be very stable. The frequency distribution of temperature differences between the four-year mean minus the Barnett and Ott (1976) values is given in Table 1. There is a seasonal variation in these differences, with the mean TRANSPAC values tending to be warmer in January and September and colder in the remaining months. The overall trend is to a warm bias in the TRANSPAC mean fields relative to the

Table 1. Number of occurrences of temperature differences (C) between Barnett and Ott (1976) mean surface temperature and the 1976-79 TRANSPAC values at 2 deg lat between 30 and 50 N along 145, 155, 165 and 175 W.

	Jan	Mar	May	Jul	Sep	Nov	Total
< -2.1 °C				1			1
-2.0 to -1.6				1			1
-1.5 to -1.1			2	1	1		4
-1.0 to -0.6		4	7	3	1	4	18
-0.5 to -0.1	2	11	13	12	10	13	61
0 to 0.4	16	18	13	13	12	16	89
0.5 to 0.9	17	9	7	6	12	6	57
1.0 to 1.4	7			2	4	4	17
1.5 to 1.9				3	1		4
> 2.0 °C					1		1

Barnett and Ott fields. The large positive and negative values tend to be found in regions of large sea surface temperature gradient regions. In these cases, it appears that the gradients in the Barnett and Ott fields are not as smooth as in the TRANSPAC analyses, which leads to large differences in the point values.

One method of estimating the natural variability of temperature within this domain is to form the monthly standard deviations. Because only four years are available, the standard deviations are calculated over three-month intervals, and thus involve a sample of 12 values. Examples of the standard deviation fields at selected depths are given in Fig. 1. The winter fields at 0 and 60 m (Fig. 1a) are nearly identical since the mixed layer is typically greater than 60 m. The primary features on these charts are the centers at 170 E and 150 W. The western center extends to 200 m whereas the eastern center is greatly diminished at this depth. During the summer period, the variability at the surface (Fig. 1b) is a maximum at 165 E, and there are two secondary centers at 140 W and 165 W. The zone of maximum variability has clearly shifted northward relative to the winter period. There is also a large decrease in variability at 60 m relative to the surface during the summer, when the mixed layer depth is frequently smaller than 60 m. As in winter, the variability at 200 m is much larger in the western region compared to the remainder of the domain. This deep variability is associated with eddies in the Kuroshio extension region (White and Bernstein, 1979; White, et al., 1980).

(As this manuscript was being prepared, the author discussed the credibility of the TRANSPAC analyses with Dr. Warren White, who is one of the leaders in the TRANSPAC program. Dr. White expressed the opinion that the temporal and spatial data coverage is inadequate to resolve the eddies in the

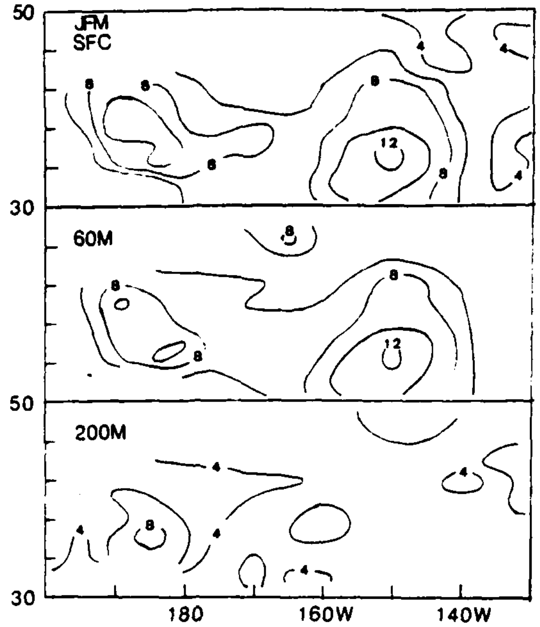


Fig. 1. (a) Temperature standard deviations during January-February-March for 1976-79 at surface (top panel), 60 m (middle), and 200 m (bottom).

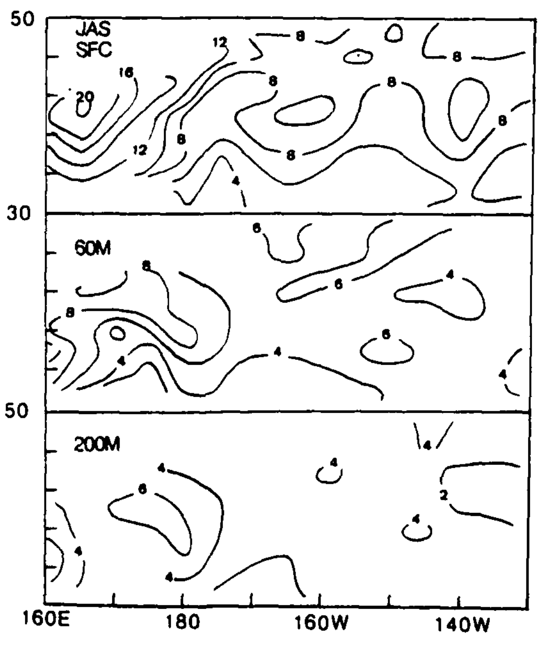


Fig. 1. (b) Similar to Fig. 1a except for July-August-September.

region west of the dateline and in the California Current region. Furthermore, the analysis scheme can not resolve these eddies on a 2 deg lat by 5 deg long grid. Consequently, Dr. White suggests caution in interpreting the analyses in these areas. Furthermore, the seasonal variation in the data coverage north of 45 N or south of 35 N due to ship track changes also make the analyses in these areas less reliable. These comments should be kept in mind in the following discussions of the analyses over the entire domain.)

3. Summary of anomalies

A schematic illustration of the significant cold and warm anomalies that developed during 1976-79 is given in Fig. 2. A more detailed description of these anomalies will be provided in the following two sections. The purpose of this diagram is to illustrate the approximate longitude and magnitude of the center of each anomaly. No indication of the latitude of the center can be given in such a two-dimensional view. Cases of multiple anomalies at the same longitude in Fig. 2 are indicative of a north-south oriented pattern. Although anomalies exist at all longitudes, one can detect predominate locations at 170 E and about 145 W. There are also a number of centers near 170 W. These locations are consistent with the maxima in variability found in Fig. 1. The scale that is implied seems to be approximately 2000 km or more. However, the number of features existing during any month varies considerably.

There is a variety of evolutions of anomaly intensity illustrated in Fig. 2. In some cases (e.g. warm anomaly 15 and cold anomaly 37), the maximum intensity is observed during the initial month. Thus, the time resolution of these analyses is inadequate to trace the development of the anomaly. Occasionally, the maximum amplitude is found during the month preceding the disappearance of the anomaly. Again the monthly time scale of the analyses is clearly inadequate to describe this aspect. The longer lasting anomalies tend

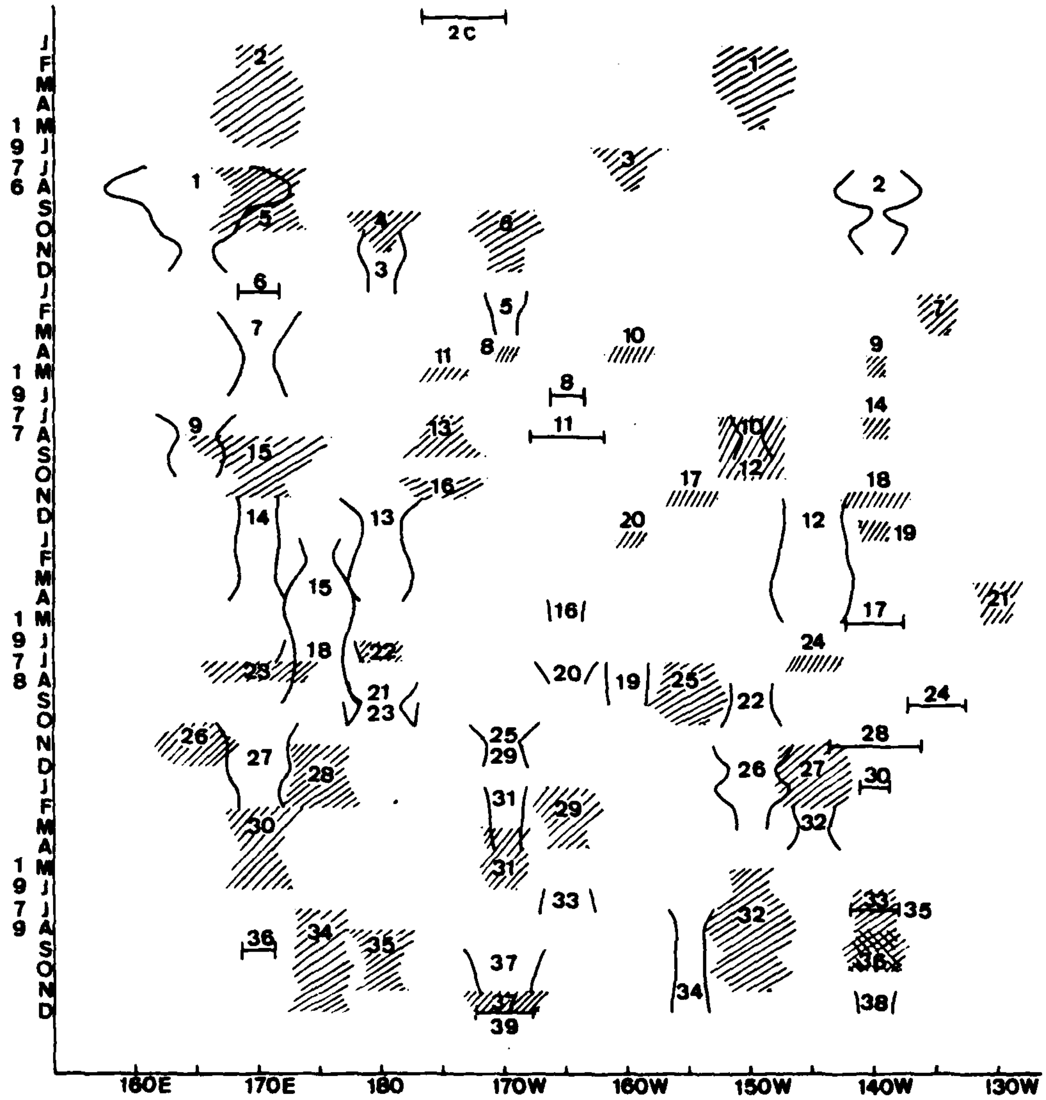


Fig. 2. Magnitude (indicated by width of the envelope) of warm (cross-hatched) and cold (open lines) anomalies during 1976-79. Each anomaly is plotted at a typical longitude of the center during the evolution and the area here does not represent the areal extent of the actual anomaly.

to have increases and decreases in magnitude (the central amplitudes in Fig. 2 are not necessarily at the same location in each month). For example, cold anomaly 2 and warm anomaly 32 have at least two periods of maximum amplitude. In these cases, a model of rapid anomaly growth and a slow decay due to dispersive processes, or perhaps feedback to the atmosphere, does not seem to apply. The mechanisms by which these long-lasting anomalies are reinforced, or new anomalies are superposed, need to be studied.

Some of the highly transient features in Fig. 2 may be due to data coverage and the analysis procedures. Comparison with the ocean model predictions, which will have much better time resolution, may indicate the reality of these features. In some cases, it may be necessary to examine the original temperature profiles to resolve the question of whether these features are real or are a product of the analysis technique.

4. Cold anomaly development

Table 2 is a listing of the significant cold anomalies that developed during the period. This is not an exhaustive list of cold anomalies; rather Table 2 includes only those cold anomalies that seemed to be new developments. Other cases which were revealed by removal of a warm surface layer, or which simply represented an intensification of a pre-existing cold anomaly will be discussed later. Many single grid point cold anomalies, especially west of 170 W, are also not listed as they are highly transient features which are not well resolved by the 5 deg long and monthly scales of the analysis. Although the selection of cases is somewhat subjective, those included are thought to be significant departures from normal conditions.

The cold anomalies (CA) listed in Table 2 range in intensity from -0.71 C to -4.48 C in CA 1. The range of lifetimes (not shown) is from only one month to nearly a year. A somewhat expanded description of several of these cold

Table 2. Examples of development of cold anomalies or rapid transitions from warm to cold anomalies during January 1976-December 1979. The maximum intensity at the indicated location does not necessarily occur during the initial month. Each of the case numbers with an asterisk is discussed in the text. An indication as to whether the dominant process is surface-based or thermocline-related or a mixture is also given.

No.	Initial Month	Maximum Intensity (C)	Location Lat.	Location Long.	Predominant Process Surface	Predominant Process Thermocl	Predominant Process Mixed	Uncertain
1*	7/76	-4.48	40	165 E			x	
2	7/76	-2.12	42	140 W	x			
4	12/76	-1.44	34	165 E			x	
5	1/77	-0.99	44	170 W			x	
6	1/77	-0.96	38	170 E	x			
7*	2/77	-1.96	40	175 E			x	
9	7/77	-1.92	36	175 E			x	
10	7/77	-1.00	47	150 W			x	
11	8/77	-1.82	40	165 W	x			
12*	11/77	-2.06	36	150 W	x			
18	5/78	-2.07	38	175 E		x		
20	7/78	-1.45	46	165 W	x			
21	7/78	-2.06	42	175 E			x	
22	8/78	-1.00	50	150 W	x			
24	9/78	?	30	135 W				x
30	1/79	-0.71	46	140 W			x	
33	6/79	-1.13	34	165 W	x			
34	7/79	-1.01	32	155 W		x		
35	7/79	-1.06	48	140 W			x	
36	9/79	-0.82	40	170 E	x			
37	9/79	-2.01	38	160 W			x	
38	11/79	-0.96	42	140 W				

anomalies will be presented in this section. An abbreviated description of the remainder is given in Appendix A. The major focus of these short descriptions is to indicate those features that are likely to be predicted by a mixed layer model. A preliminary indication is given in Table 2 as to whether the predominant process involved in each of these cold anomalies is surface-based (and thus likely to be predicted by the mixed layer model), or due to thermocline-related processes, or a mixture of these two processes, or is uncertain at this time. It is hoped that the summary in Table 2 and the descriptions below and in Appendix A will assist in the selection of cases for validation of ocean prediction models.

a. Large-scale, rapid-transition case. The development and intensification of an extensive cold anomaly (CA 1) at the surface during July and August 1976 are shown in Fig. 3. This case is especially dramatic as it occurs after at least (the first available map is January 1976) six months of above-normal temperatures at all depths. The initial conditions at the surface during June 1976 are shown in Fig. 3a. During July 1976 (Fig. 3b), the anomaly centers at 42 N, 165 E and at 36 N, 165 E are -2.54 C and -2.43 C, respectively. The southern center appears to be related to a deep (at least to 300 m) and cold anomaly at 34 N (not shown). The surface anomaly covers the largest area during August 1976 (Fig. 3c). At this time it has eliminated the surface signature of a warm anomaly (WA 5) near 42 N, 175 E during July 1976. The maximum intensity (-4.48 C) for this anomaly occurs during August near 40 N, 165 E. During September (Fig. 3e), the northern branch of the anomaly is sustained, although the center of -2.34 C is displaced to 44 N, 175 E. The southern center diminishes during September, perhaps in response to the arrival of an extremely intense warm anomaly at 60 m and below. During October 1976 (Fig. 3e), a two-celled structure appears with centers at 42 N, 180 and

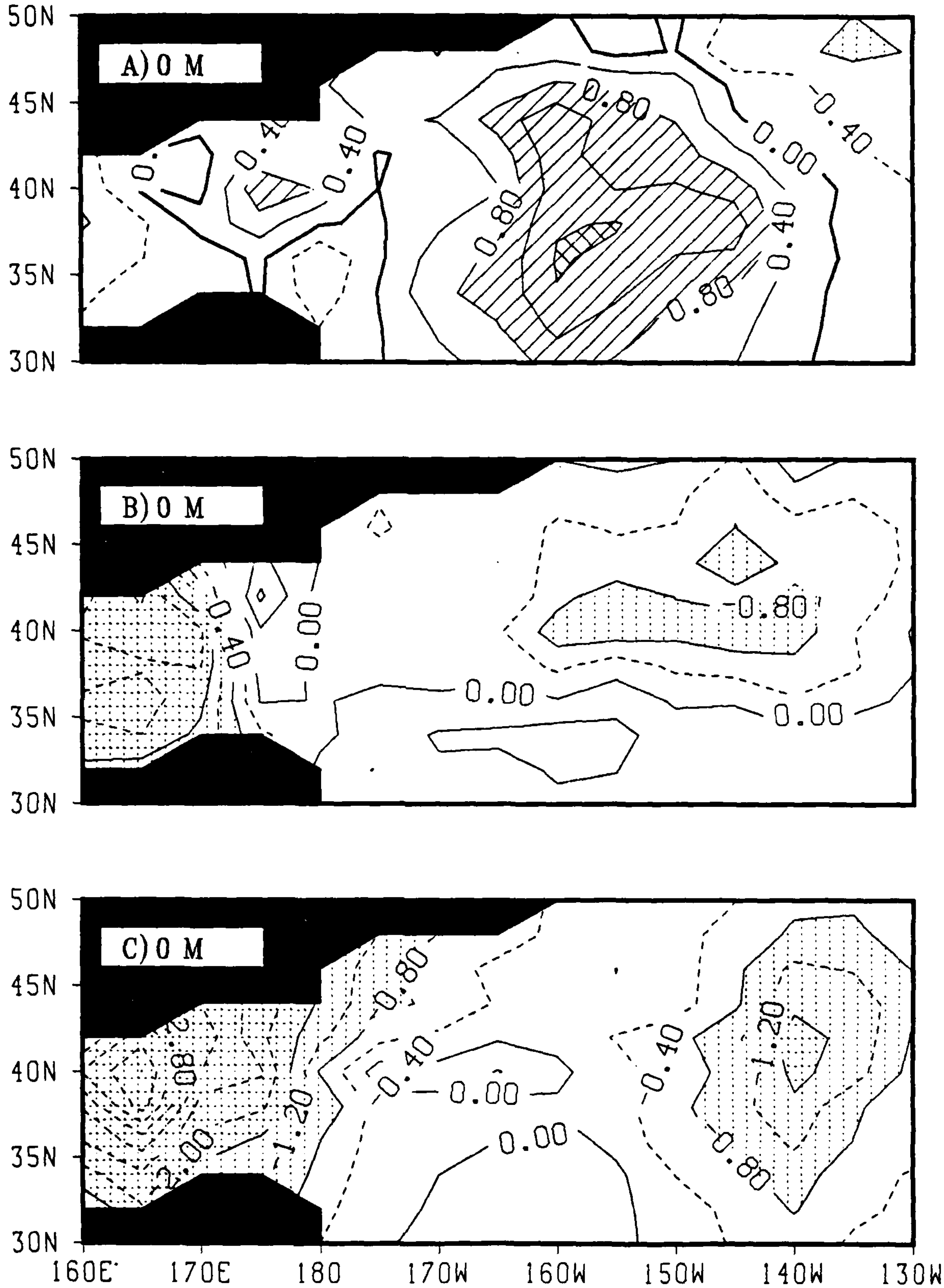


Fig. 3. Surface temperature anomaly (^{o}C) during (a) June, (b) July and (c) August 1976. Hatched (cross-hatched) areas indicate greater than 0.8 ^{o}C (1.6 ^{o}C). Negative anomalies are indicated by dashed lines, with shading for values exceeding (-0.8 ^{o}C).

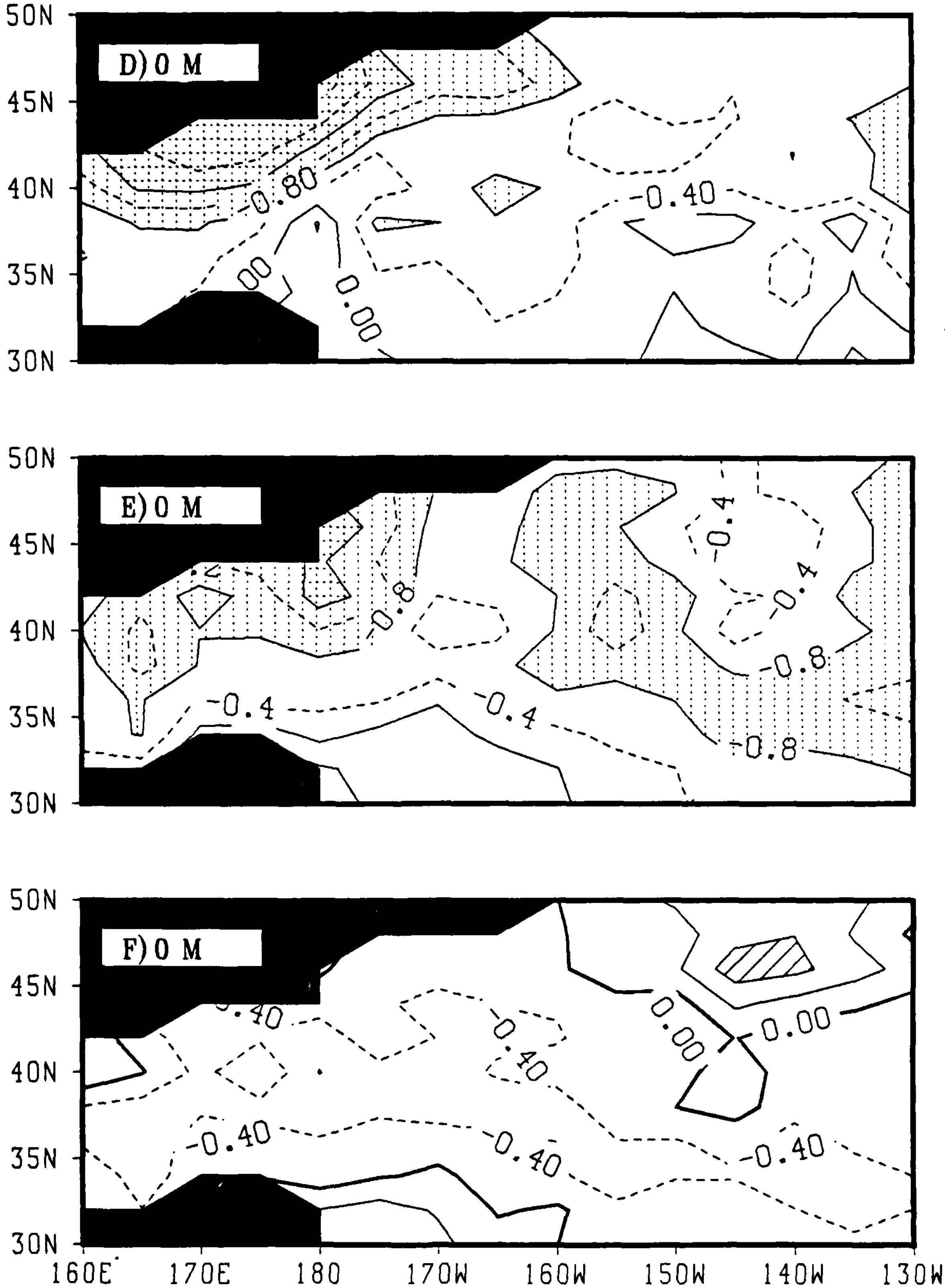


Fig. 3. (Continued) (d) September, (e) October and (f) November 1976.

39 N, 165 W. Between these two centers (-1.62 C and -1.87 C, respectively), there is a relative minimum directly above the warm anomaly WA 5. However, even this region becomes a cold anomaly center during the last month in the sequence (*Fig. 3f*).

This case should provide an excellent test for ocean prediction because of the dramatic change from predominantly warm anomalies to an intense cold anomaly. The anomaly remained above 60 m until October. Although an analysis is available at 30 m, one may have to resort to the original observations to define the vertical penetration of the cold anomaly into the relatively warm subsurface layers. The prediction model must also have the proper vertical resolution to describe the development and intensity of the anomaly.

b. Extreme deepening case. The pre-existing conditions during January 1977 are shown in Fig. 4. Most of the western portion of the domain already had below-normal temperatures to 60 m because of the strong atmospheric forcing during the preceding autumn (White and Bernstein, 1979; Haney, 1980; Elsberry, Gallacher and Garwood, 1979). At 200 m and below, above-normal temperatures persisted.

The extreme cold anomaly that develops near 40 N, 175 E during February 1977 (Fig. 5) is considered to be separate from the cold anomalies (CA 5 and CA 6) that existed during January 1976. The new cold anomaly (CA 7) extends to at least 200 m. There is now a center of -0.63 C at 38 N, 175 E, whereas the warm anomaly center at 38 N, 180 during January was +0.91 C. In addition to the extremely cold (-1.96 C) central values at the surface, there are below-normal temperatures over the western three-quarters of the domain.

The surface features begin to disperse during March 1977 (Fig. 6), and this process is continued during April 1977 (not shown) when only the northern portion of the cold anomaly is sustained. The surface signature is almost

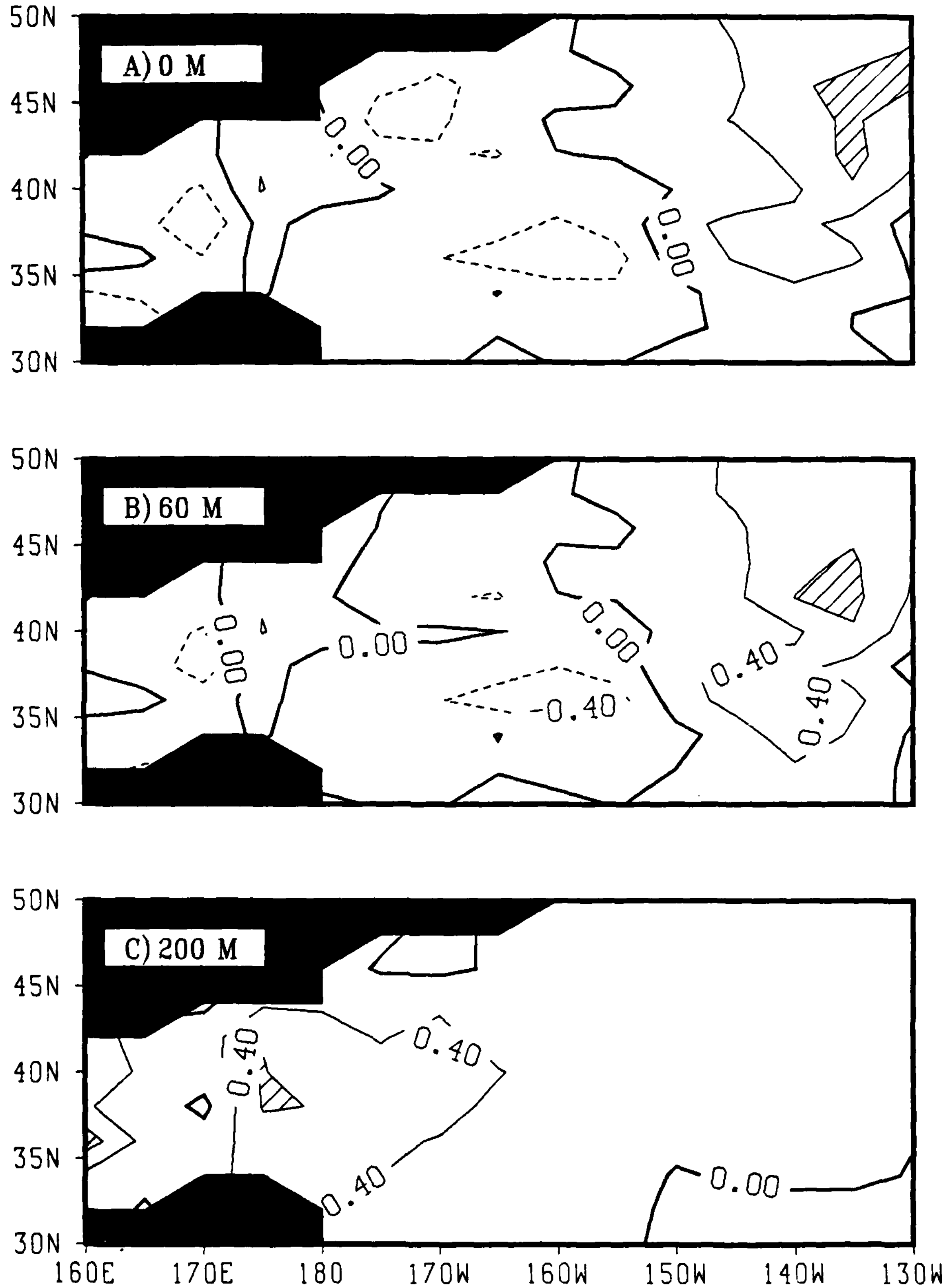


Fig. 4. Temperature anomaly during January 1977 and (a) surface, (b) 60 m and (c) 200 m.

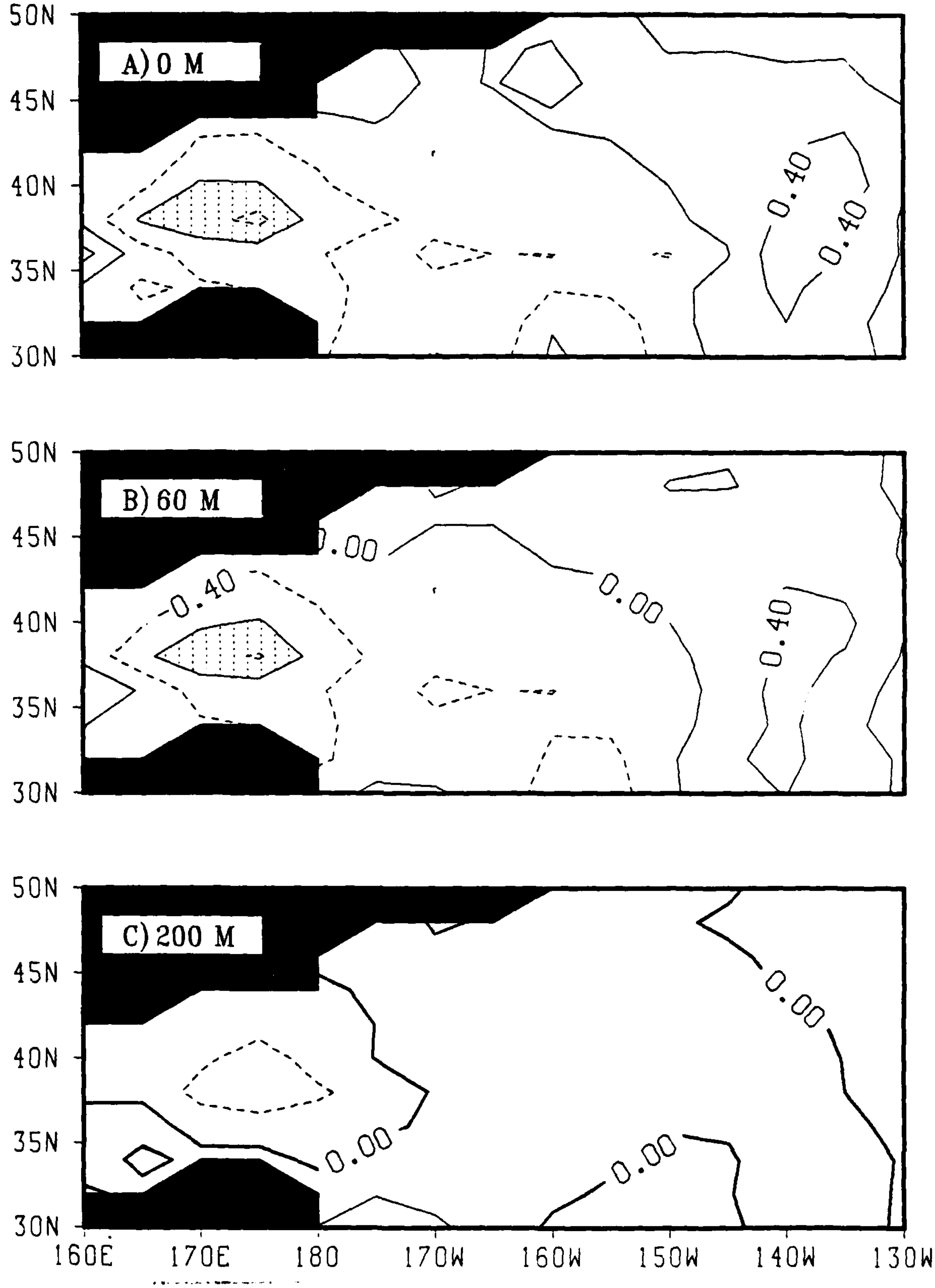


Fig. 5. Similar to Fig. 4 except for February 1977.

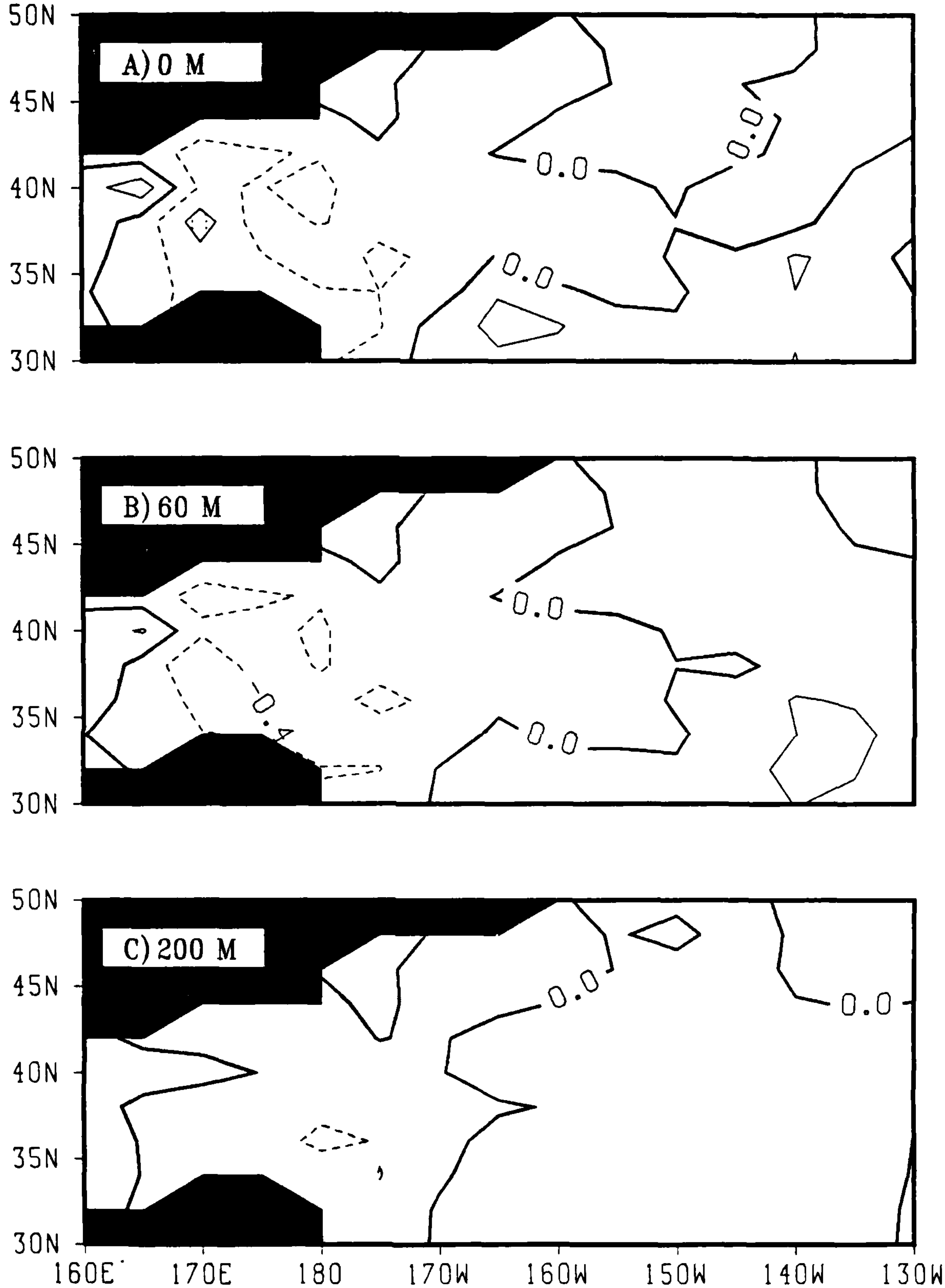


Fig. 6. Similar to Fig. 4 except for March 1977.

eliminated during May 1977, when the spring transition has presumably occurred. However, the subsurface portion of the anomaly persists throughout this period. When the warm surface layers are eliminated during June 1977, a cold surface signature reappears.

This case is a major challenge for ocean prediction. An essential feature is the extreme deepening, perhaps to 300 m during March 1977. Although the anomaly is in a generally low-temperature domain, the anomaly is relatively compact during February 1977. It is expected that the mixed layer model will be capable of predicting the near-surface evolutions given the proper atmospheric forcing.

c. Large-scale, long-duration case. As can be seen in Fig. 7a, the surface temperatures during October 1977 were above normal, especially across the north-central part of the domain. During November 1977 (Fig. 7b), a cold anomaly (CA 12) that was to persist through June 1978 began in the eastern region. The change from warm to cold anomalies from October to November 1977 is even more impressive when one considers that this is in addition to the normal cooling experienced during this period. The cooling trend is continued and expanded during December 1977 (Fig. 7c). By this time, most of the domain has below-normal temperatures. These cold anomalies had penetrated to 60 m (not shown) by December.

The vertical structure of the anomaly during January 1978 and March 1978 is shown in Figs. 8 and 9. During both of these months there is an increase in amplitude and areal extent of the surface anomalies. Both CA 12 and the cold anomaly (CA 15) in the western section have penetrated to 120 m. A warm anomaly along the eastern boundary during January has resulted in a north-south orientation of CA 12. The maximum intensity (-2.06 C) and areal extent are achieved during March 1978.

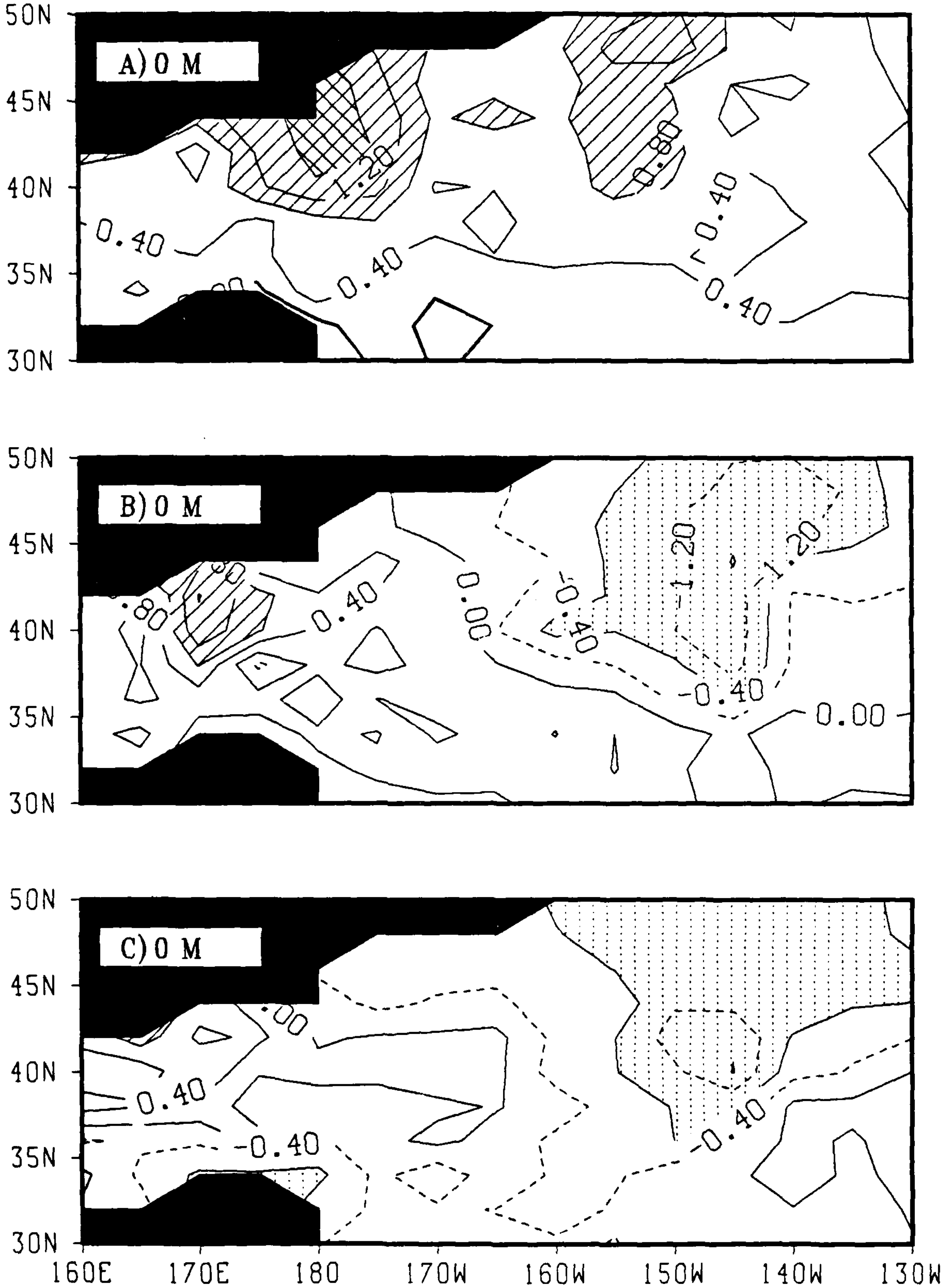


Fig. 7. Similar to Fig. 3 except for (a) October, (b) November and (c) December 1977.

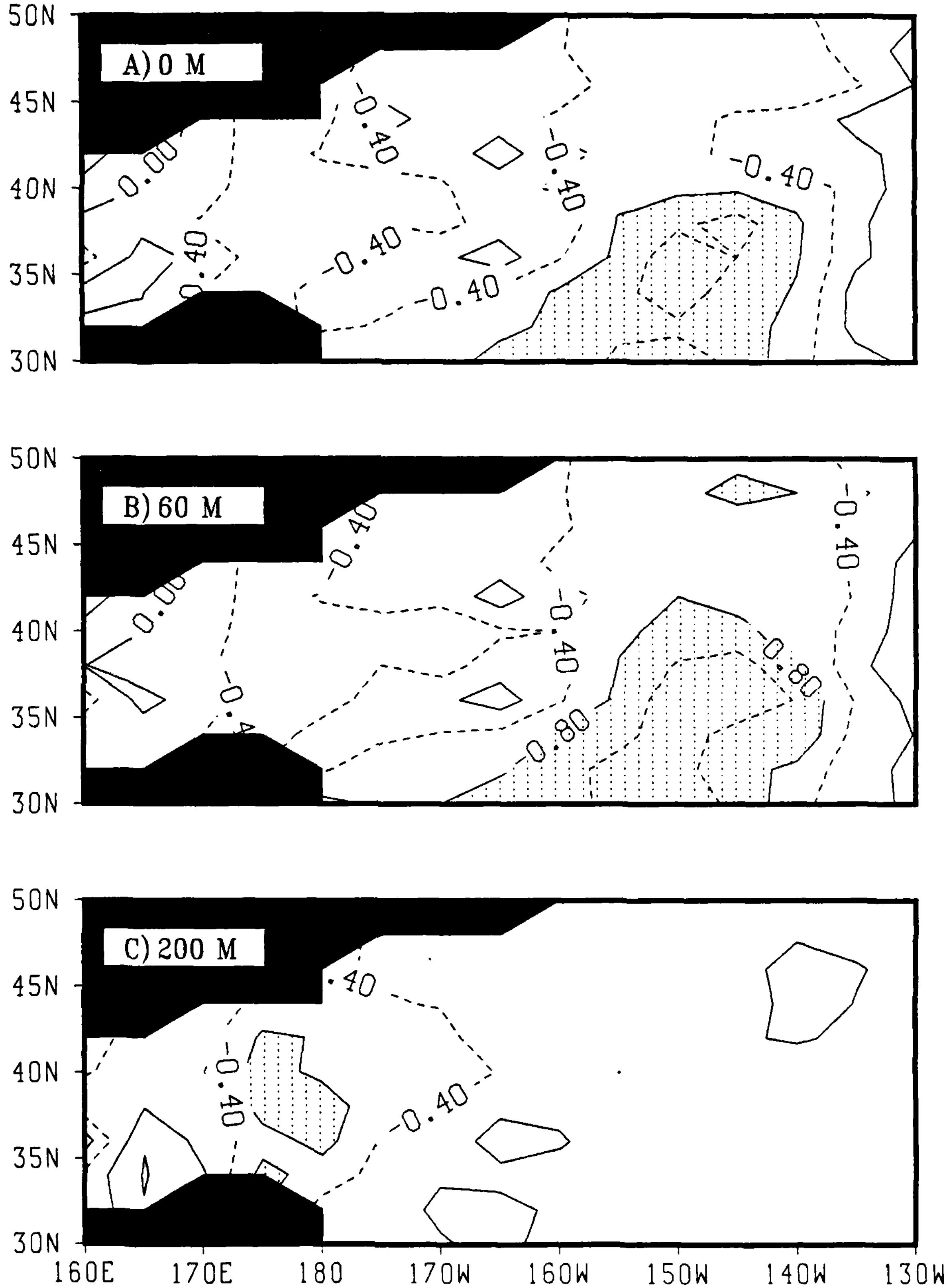


Fig. 8. Similar to Fig. 3 except for January 1978.

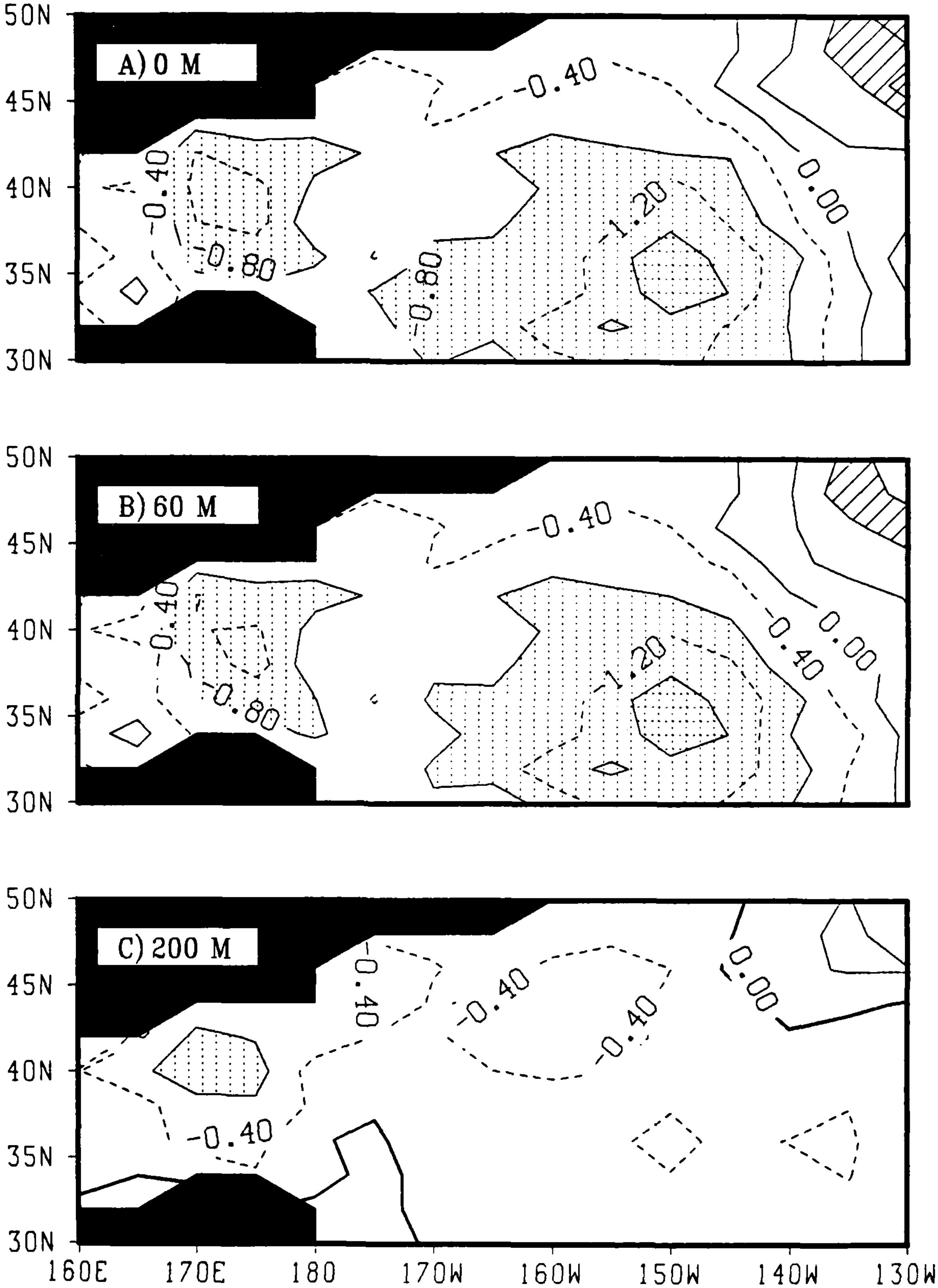


Fig. 9. Similar to Fig. 8 except for March 1978.

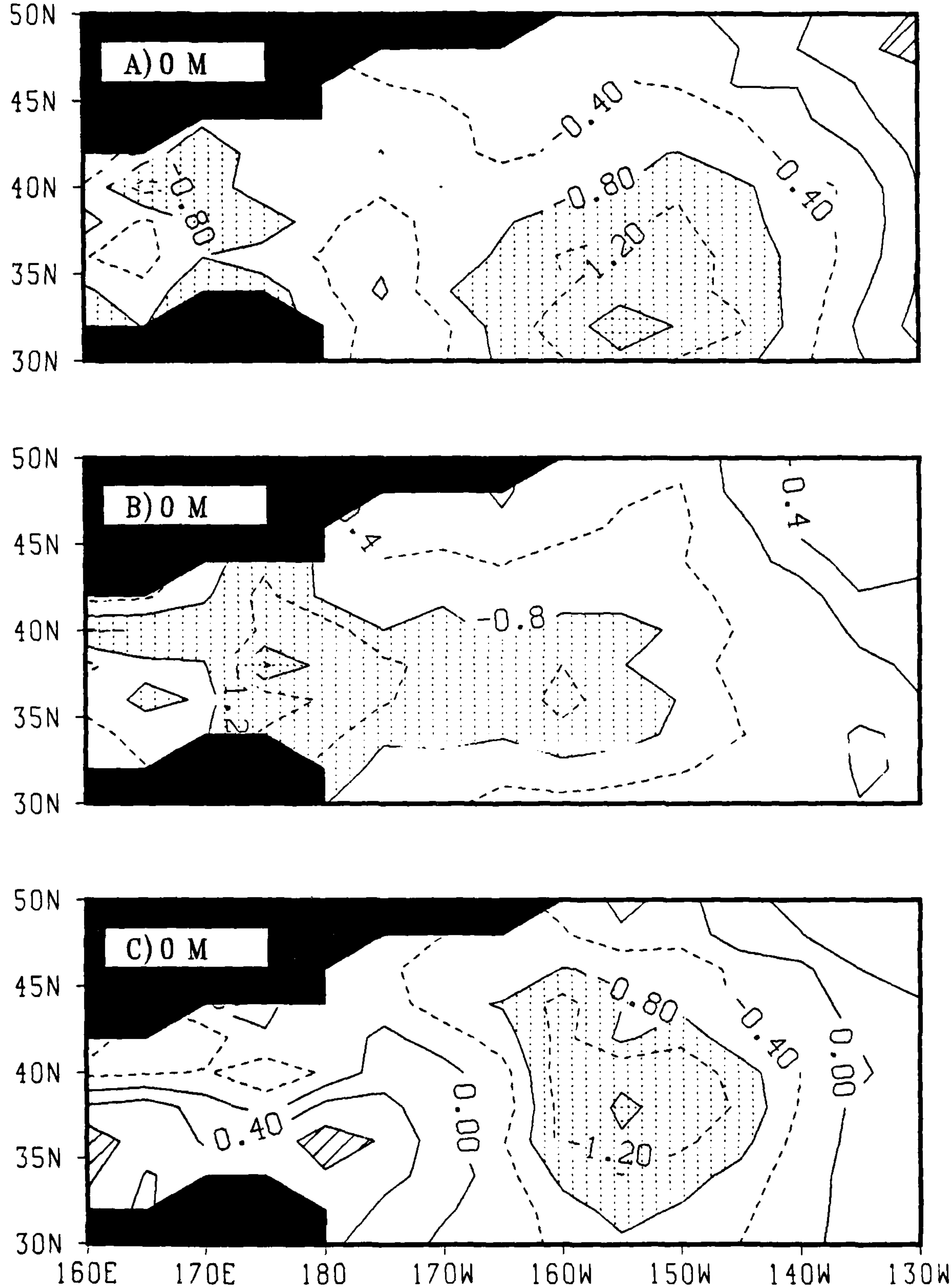


Fig. 10. Surface temperature anomaly for (a) April, (b) May and (c) June 1978.

During the following three months (Fig. 10), the cold anomaly center is maintained, although the shape of the feature is changing. It is very significant that the eastern portion of the domain remains colder than normal through June 1978. This suggests a very delayed spring transition throughout this region. Subsequent maps indicate that the region was generally cold throughout the remainder of the year. Periods of above-normal temperatures did not persist, and the conditions returned to below-normal in each case.

This extreme and persistent cold anomaly is clearly a major climatic event. It is an excellent case for testing the capability of ocean prediction models.

d. Conclusions. Each of the cold anomaly cases discussed above represented a significant departure from normal conditions. These anomalies developed during the middle of the summer, during mid-winter and during the fall, respectively. Thus, new cold anomalies can develop throughout the year. Other cases with significant departures may be found in Table 2 and in Appendix A; e.g. CA 11, CA 18 and CA 37 would seem to be especially interesting.

5. Warm anomaly development

Table 3 follows the format of Table 2, except it is a list of the new developments of significant warm anomalies. The remainder of the warm anomalies may be grouped in one of the following categories: pre-existing anomalies that were intensified during the fall deepening period or were just revealed by eliminating the surface anomaly field (see Section 7), or some cases of quite small warm anomalies that appeared to be aliased by the objective analysis scheme. As was the case for cold anomalies, numerous single grid point anomalies were not included in the tabulation.

A wide range of intensities was found for the warm anomalies, which can occur in any month. One of the strongest winter anomalies (WA 1) was already

Table 3. Examples of development of warm anomalies or rapid transitions from cold to warm anomalies during January 1976-December 1979. The maximum intensity at the indicated location does not necessarily occur during the initial month. Each of the case numbers with an asterisk is discussed in the text.

No.	Initial Month	Maximum Intensity (C)	Location Lat.	Location Long.	Predominant Process Surface	Thermocl	Mixed	Uncertain
1	2/76	2.02	34	150 W	x			
2	1/76	2.39	42	170 E			x	
3	6/76	1.89	36	160 W	x			
7	1/77	0.98	40	135 W	x			
9	4/77	0.53	44	170 W	x			
11	5/77	1.15	38	175 W			x	
12*	7/77	1.70	38	150 W	x			
13*	7/77	0.81	48	170 W	x			
14*	7/77	0.77	36	135 W		x		
15*	8/77	3.63	42	170 E	x			
16*	10/77	2.15	42	175 W		x		
19	12/77	0.75	38	135 W		x		
21	3/78	1.05	48	135 W		x		
22	6/78	1.02	36	180	x			
23	7/78	2.85	40	170 E	x			
24	7/78	1.44	48	145 W				x
25	7/78	1.97	40	165 W	x			
26	10/78	2.22	36	175 E		x		
27*	11/78	1.74	42	145 W			x	
28	12/78	2.12	34	175 E			x	
29	1/79	1.72	46	165 W	x			
31	3/79	1.23	37	170 W			x	
32*	5/79	1.79	44	160 W	x			
33	6/79	1.06	38	140 W	x			
36	8/79	1.30	34	135 W		x		
37	11/79	2.07	48	170 W				x

formed on the first month that an analysis was available. Consequently, a complete description of this case is not possible. Three anomalies that originated in the other seasons will be discussed individually below. A short description and summary of each of the other cases is included in Appendix B. Again, the primary purpose of these case discussions is to assist in the case selection for validation of ocean prediction models.

a. Large-scale development during summer. This case actually includes four warm anomaly centers (WA 12, WA 13, WA 15 and WA 16) over a five-month period. The pre-existing conditions at the surface during June 1977 (Fig. 11a) were generally below-normal temperatures over most of the domain. During July 1977 (Fig. 11b), the first two warm anomalies appear on opposite sides of a series of cold anomaly centers that stretches from the southwest corner to the north-central region. The first anomaly (WA 12) at 38 N, 150 W is already at maximum intensity (+1.7 C). It is quite likely that the second anomaly (WA 13) is actually centered off the grid. The center shown in Fig. 9b at 48 N, 170 W is on the edge of the grid.

The appearance during August 1977 (Fig. 11c) of two major warm anomaly centers (WA 12 and WA 15) with an intermediate cold anomaly (CA 11) creates one of the most remarkable patterns in the entire series. The central value (+3.63 C) of WA 15 at 42 N, 170 E is the largest value that occurred during the 48 months. It is important to notice that this center is located in a region that had below-normal temperatures during the previous month. Consequently, the temperature change during this month is very extreme. The previously existing centers (WA 12 and WA 13) are sustained during August. WA 12 is now oriented north-south and covers the eastern one third of the domain. The center of WA 13 is found along the northern edge at 48 N, 175 W, and it is again likely that much of the anomaly lies off the grid. Finally, the CA 11

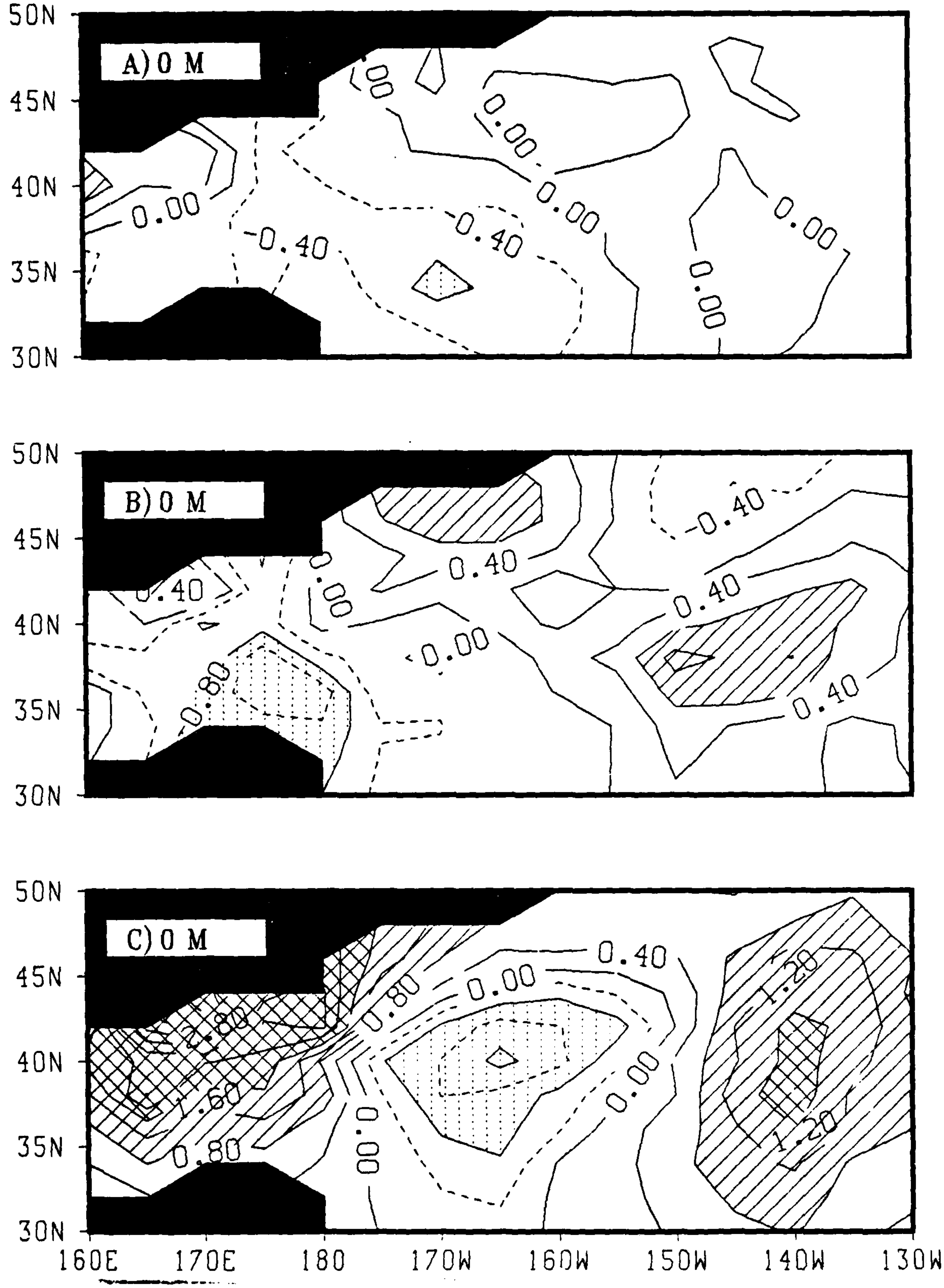


Fig. 11. Surface temperature anomaly for (a) June, (b) July and (c) August 1977.

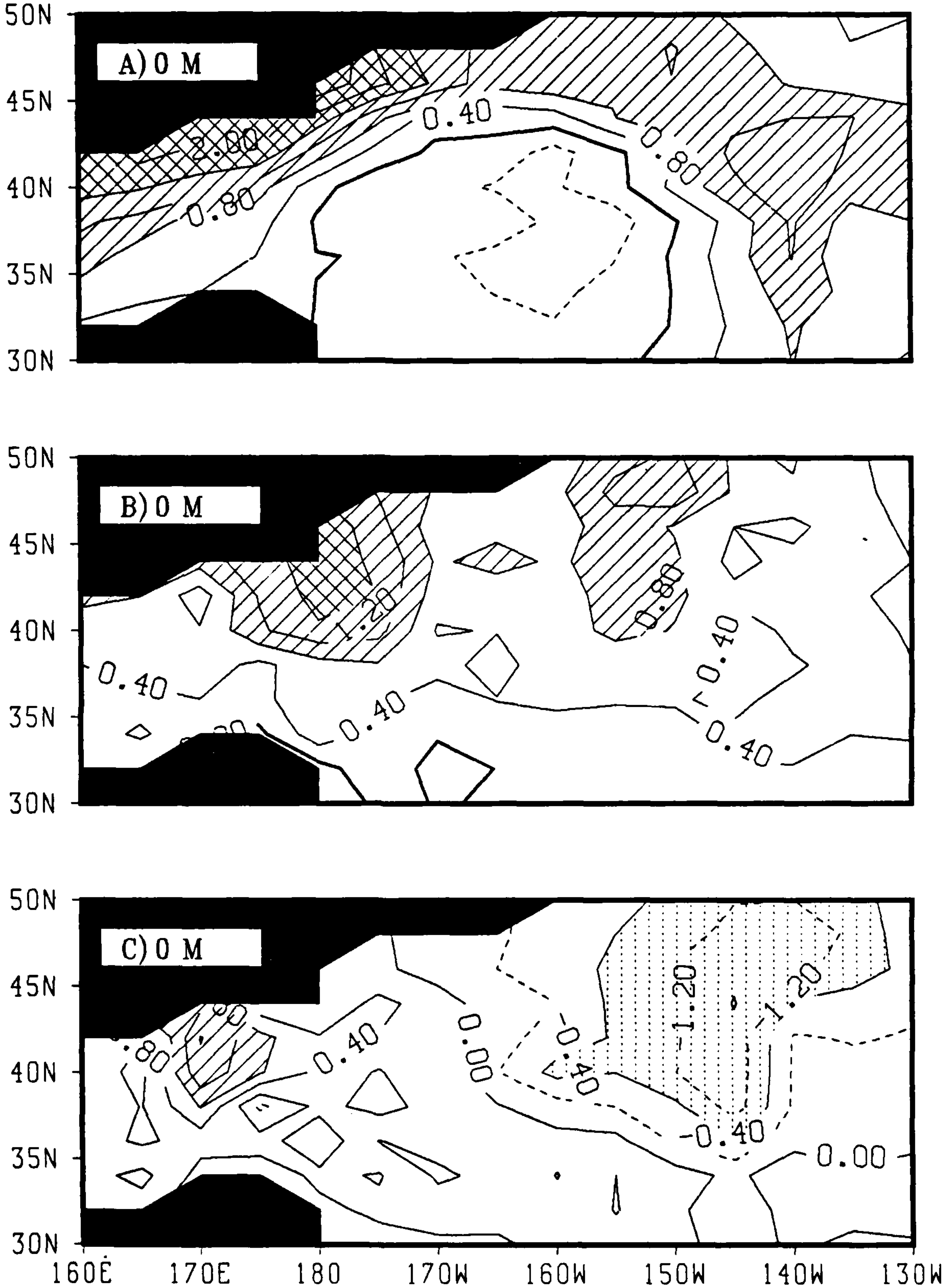


Fig. 12. Surface temperature anomaly for (a) September, (b) October and (c) November 1977.

at 40 N, 165 W between these centers is also quite intense (-1.82 C). It is of considerable interest to determine whether the observed local atmospheric forcing can produce such an extreme event.

During September 1977 (Fig. 12a), the basic pattern of a series of warm anomalies across the upper portion and eastern one third of the domain is maintained. However, the cold anomaly (CA 11) has almost disappeared. In fact, there is now a slightly warm area at 40 N, 165 W, which indicates that there has been considerable warming in this region during the month. By October 1977 (Fig. 12b), the warming in the central area has completely eliminated any vestiges of CA 11. Almost the entire domain now has above-normal temperatures. The center (2.15 C) at 42 N, 175 W is considered to be different from WA 13 and WA 15. Although the new center (WA 16) formed within the envelope of the pre-existing centers, its intermediate location and its southward extension seem to distinguish WA 16 from WA 15, which has markedly decreased in intensity along the western edge. This example indicates a difficulty in following the anomaly centers on monthly time intervals. It is perhaps just as arbitrary to not attach a new number to the center (1.59 C) at 48 N, 150 W during October 1977. The warm area becomes more evident as the eastern one third of the domain no longer has significantly above-normal temperatures. The double-center in this area appears to be a little suspicious, and should be verified from the raw observations.

The demise of the warm anomaly pattern during November 1977 (Fig. 12c) is especially dramatic in the eastern Pacific. An extensive cold anomaly (CA 12) spreads over this region. There is also a significant cooling in the western half, although a deep warm anomaly remains at 42 N, 170 E.

Nearly all of the warm anomalies described during this five-month period appear to be quite shallow. One expects that the extreme above-normal

surface temperatures must not be very deep. For example, the band of warm anomaly centers along the northern edge during September 1977 has below-normal temperatures below it at 60 m. Consequently, the vertical temperature profiles below the anomaly centers will be an important aspect of the prediction model verification.

b. Warm anomaly during autumn-winter. Although there was a warm anomaly in the winter case shown in Fig. 7, the center was on the eastern edge of the domain. In this sequence, the warm anomaly is again in the eastern portion, but it is well-situated on the grid. The surface temperatures (Fig. 13a) were already above normal in the east-central region during the month prior to maximum intensity. At 60 m (not shown), almost the entire region had below-normal temperatures.

An intense (1.74 C) and extensive warm anomaly (WA 27) is found (Fig. 13b) at the surface during November 1978. At 60 m (not shown) below the surface, the temperatures have remained distinctly below normal under the region of the warm anomaly at the surface. Consequently, there are large vertical gradients between these levels.

During December 1978 (Fig. 13c), the surface warm center remains almost as intense (1.68 C vice 1.74 C during November), but a warm anomaly is now found at 60 m, at least in the northern section. Thus, the anomaly has deepened while maintaining intensity. This trend is continued during January 1979 (Fig. 14). Although the horizontal dimensions of the surface anomaly have shrunk, there is a well-defined center at 60 m (Fig. 14b). At 120 m (Fig. 14c), there is not a warm center at this location, but there is a relative maximum within the general area of below-normal temperatures. The warm anomaly disappears during February 1979 (not shown).

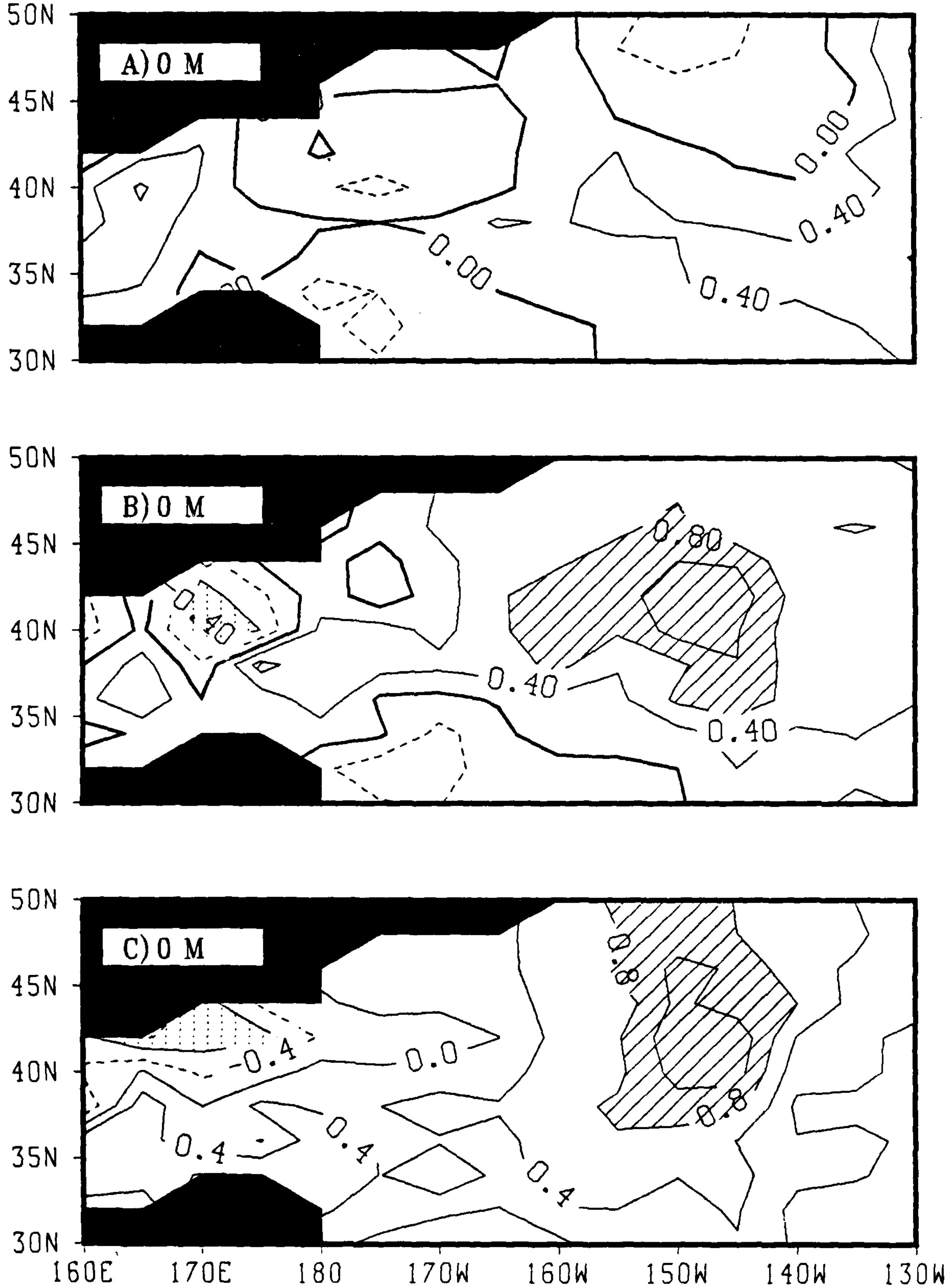


Fig. 13. Surface temperature anomaly for (a) October, (b) November and (c) December 1978.

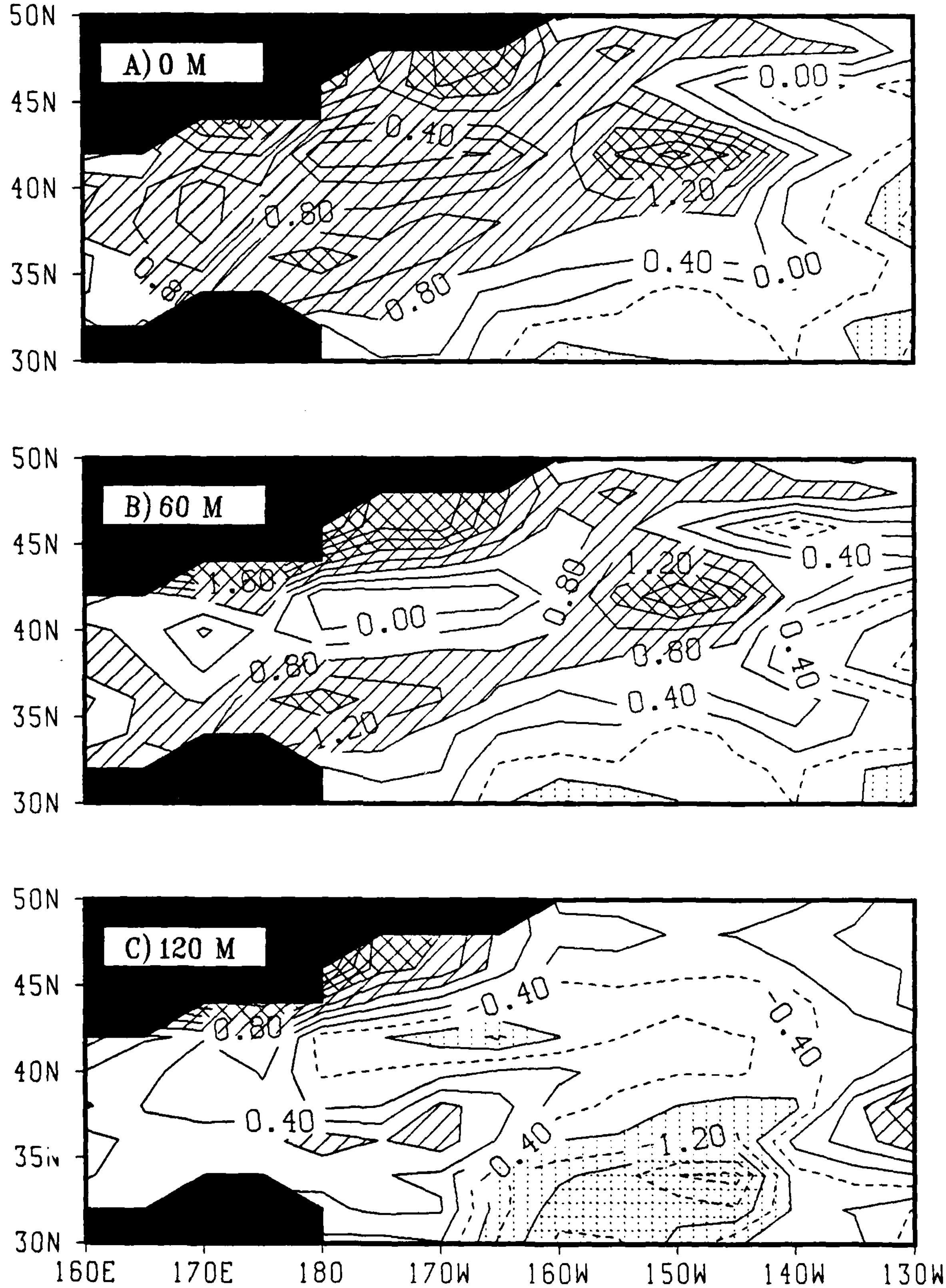


Fig. 14. Temperature anomaly during January 1979 at (a) surface, (b) 60 m and (c) 120 m.

This anomaly evolves from a broad surface feature to a concentrated center with above-normal temperatures to at least 60 m. The maintenance of the warm anomaly during the autumn and early winter deepening makes this case an interesting test for the ocean prediction model.

c. Warm and deep anomaly. The word deep here does not refer to a thermocline feature to 300 m. Rather this case (WA 32) involves the development of a warm surface anomaly within a generally warm upper ocean. This is in contrast to the case in Figs. 11 and 12 in which the warm anomaly is limited to the surface, with below-normal temperatures at 60 m. In the case to be discussed, the surface signature of high temperatures may not have an abnormal vertical temperature profile.

The roots of this anomaly may be traced to the warm anomaly in the northeast quadrant of Fig. 14. Although WA 27 diminished in intensity during the subsequent months, this region had above-normal temperatures through April 1977 (not shown). A double center appears in the northeast quadrant on the May 1979 surface map (Fig. 15a). The more intense center at 50 N, 150 W is quite suspicious, although there had been a warm center along 50 N during April. This northern center is also reflected on the 60 m map in Fig. 15b. During June 1979 (Fig. 16), there are a number of warm centers in the eastern quadrant on the surface map. Rather than a double center as in May 1979, there is a single center (0.93 C) at 46 N, 155 W. There is also a well-marked warm anomaly at 60 m (Fig. 16b) during June 1979.

An intense and extensive surface anomaly appears at 44 N, 160 W during July 1979 (Fig. 17). Under the eastern portion of this anomaly there is a warm center at 60 m. Thus, the vertical temperature profile in this area would be above normal to at least 60 m, whereas surface-forced warm anomalies during summer are usually quite shallow.

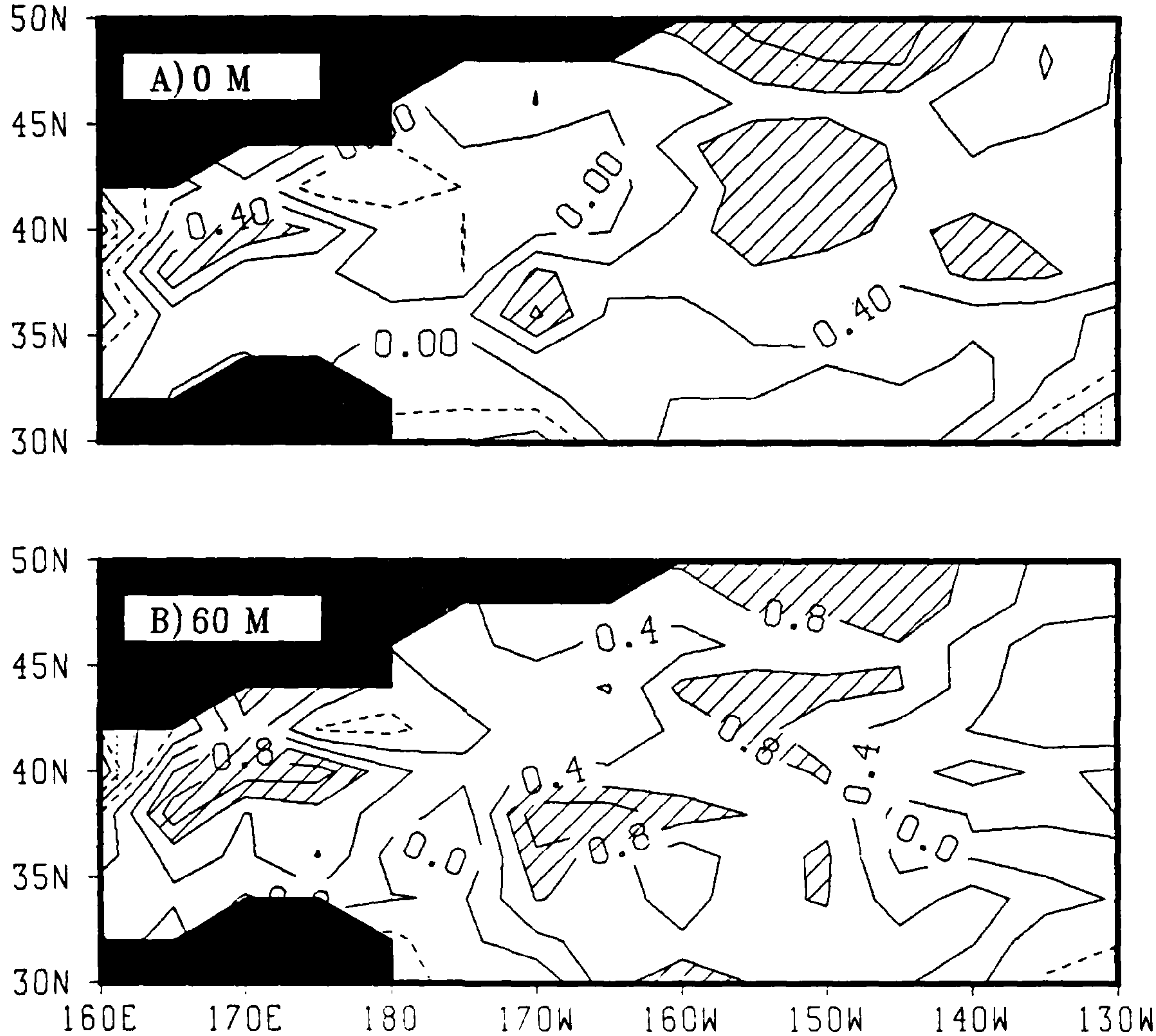


Fig. 15. Temperature anomaly at (a) surface and (b) 60 m during May 1979.

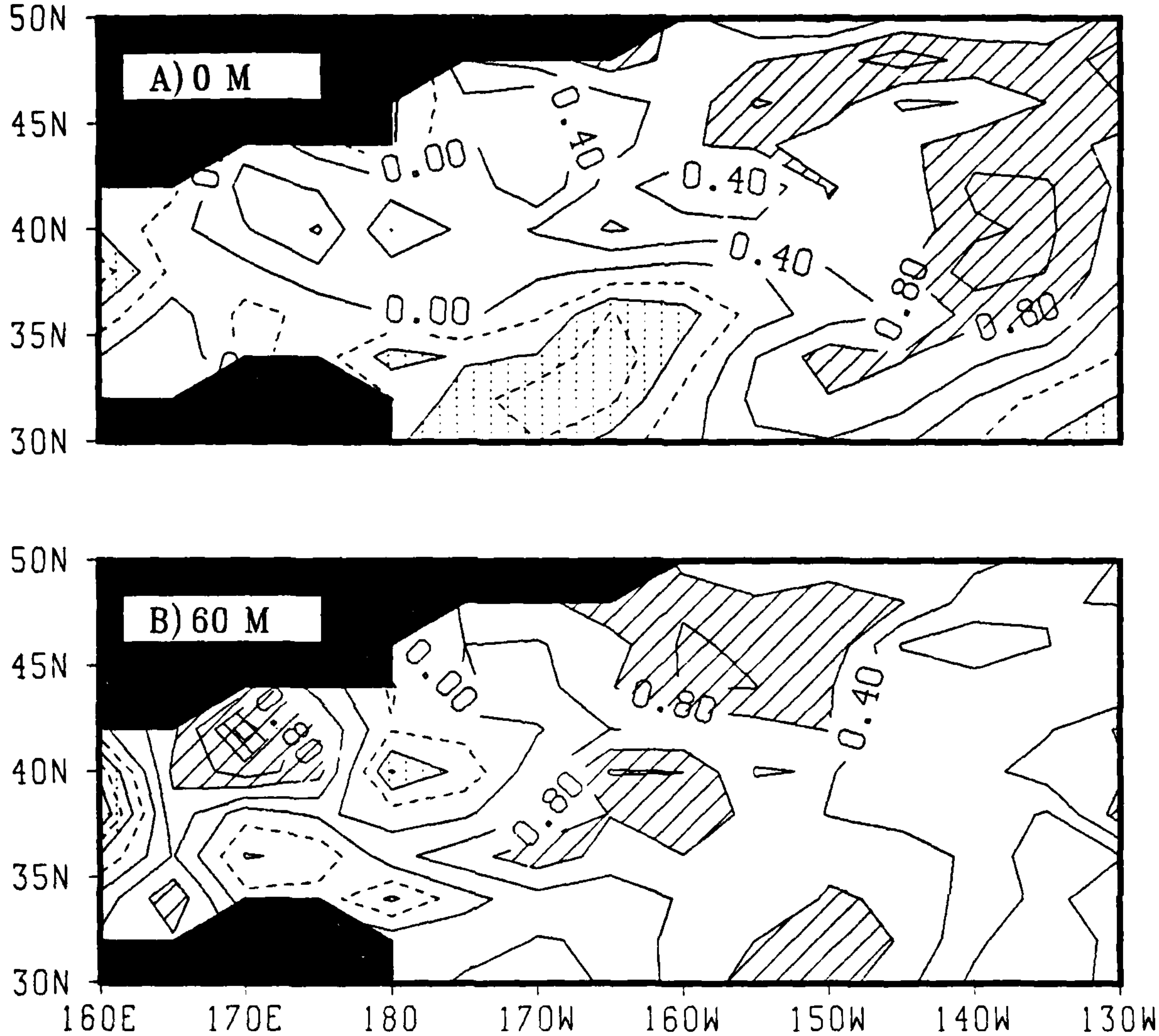


Fig. 16. Similar to Fig. 15 except during June 1979.

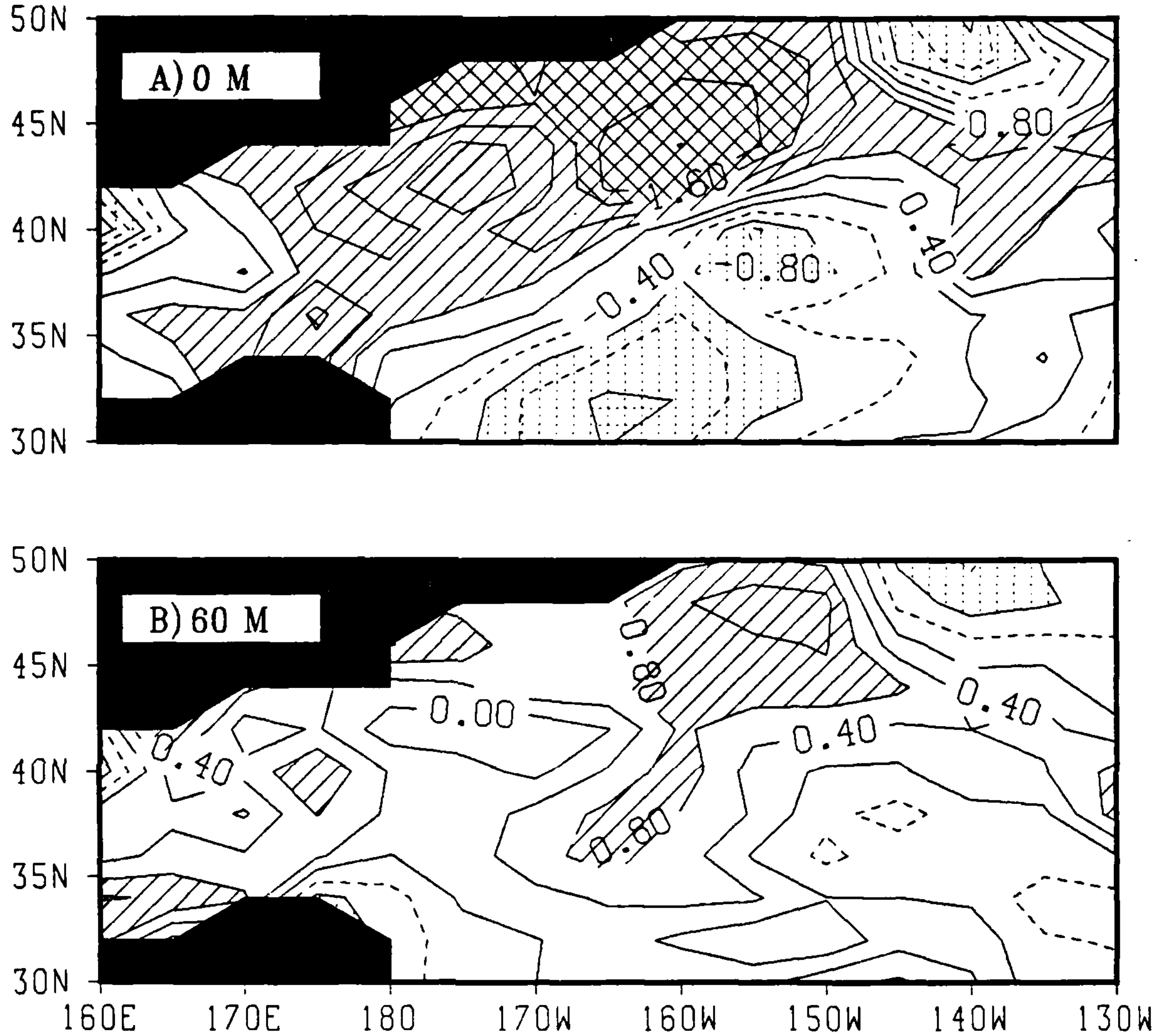


Fig. 17. Similar to Fig. 15 and 16, except during July 1979.

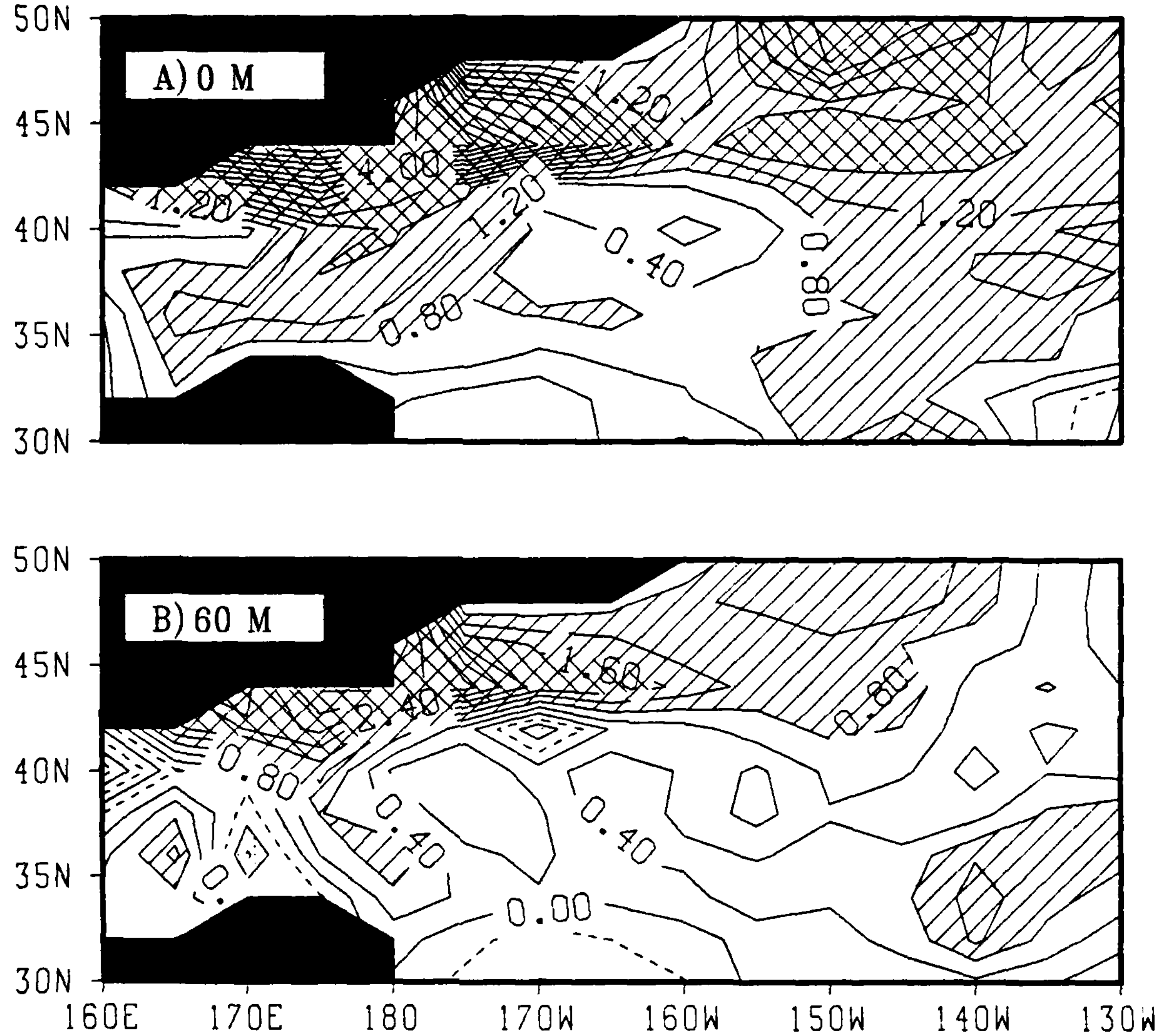


Fig. 18. Similar to Figs. 15-17, except during August 1979.

The subsurface center is found at 48 N, 150 W during August 1979 (Fig. 18b). There is an intense (> 2.2 C) surface signature to this feature along the northern edge and a secondary center farther south (Fig. 18a). It has been noted above that these double centers adjacent to the boundary appear to be suspicious and may be related to the data distribution or the objective analysis technique. However, each of the surface centers is present during the following two months (1.16, 1.28 and 2.01 C during August, September and October respectively).

This example illustrates the effects of a warm upper ocean initial state on the surface anomaly development. Rather intense surface centers are found, and there appears to be a downward transfer of this heat to 60 m during October 1979. The distribution of heat over the upper 100 m may then be an important aspect of the ocean prediction problem.

d. Concluding remarks. Two of the cases discussed above reached their maximum intensity during the summers of 1977 and 1979. There were also intense warm anomaly developments (WA 23 and 25) during the summer of 1978. However, there are also significant warm anomalies during the winter (e.g. WA 1 and WA 2, in addition to WA 27 discussed above). The relative importance of local versus remote atmospheric forcing in the development of these significant anomalies should be determined.

6. Enhancement of subsurface anomalies

In the above sections, we have discussed the formation of new cold or warm anomalies. Many of these surface-based features appear to be related to the atmospheric forcing. In other cases, there is a deep thermocline feature which may or may not have had a surface signature. It was also noticed that each autumn there appeared to be an enhancement of the subsurface anomalies. Both warm and cold anomalies appeared to increase in intensity and they

frequently would acquire a banded structure. Because of the occurrence of the phenomena during each of the four autumns (see list in Table 4), a discussion of one of the cases is included. It should also be noticed in Table 4 that a similar enhancement of anomalies sometimes occurred during the spring. However, the spring period cases appear to be deeper and to involve relatively weak enhancement of cold anomalies.

During autumn 1977, the surface maps (Fig. 12) were dominated by the warm anomaly centers WA 12, 13 and 15. The corresponding 60 m maps are shown in Fig. 19. The September 1977 map at 60 m (Fig. 19a) has little correlation with the surface map (see Fig. 12a). A much smaller horizontal scale is found at this level compared to the surface map. Relatively small changes appear to occur at the surface during October 1977 (Fig. 12b), except that there is a relatively warm layer covering the surface over most of the domain. Nevertheless, the features at 60 m (Fig. 19b) appear to be enhanced and more organized compared to the previous month. There are three warm anomaly centers along the center of the domain. Both the western and eastern anomaly centers exceed 1.0 C and have little indication of a prior history. The enhancement of the cold center at 50 N, 175 W is also quite remarkable in view of the significant warm anomaly at the surface. The series of cold centers across the southwest quadrant is also an indication of the enhancement and organization at 60 m.

During November 1977 (Fig. 19c) the warm anomalies at 60 m in the eastern region are considerably enhanced compared to the previous month. The organization of the warm anomaly centers at 60 m does begin to show more correlation with the surface map. This is probably an indication that the mixed layer depth is approaching 60 m during November 1977. Later in the winter, the features at 60 m will assume the character of the surface map.

Table 4. Cases of subsurface enhancement and/or banded organization of anomalies. The temperature anomalies are generally for 60 m, except when indicated by a # symbol. Each of the case numbers with an asterisk is discussed in the text.

AUTUMN

Month	Anomaly	Lat.	Long.	Temperature Anomaly (C) This Month	Prior Month
10/76	WA 6	44	170 W	1.84	1.33
10/76	CA 3	36	180	-1.00	> 0
10/77*	WA 16	40	180	1.54	< 0
11/77*	WA 17	34	155 W	1.27	> 0
11/77*	WA 18	40	140 W	1.70	0.5
11/77*	CA 13	36	180	-1.07	-0.61
11/77*	CA 14	34	170 E	-0.80#	-0.2
1/78	CA 15	40	175 E	-0.80#	-0.4
1/78	WA 20	34	160 W	0.68#	< 0
9/78	CA 23	36	180	-1.80	-0.8
10/78	CA 25	32	170 W	-1.71	-0.19
10/78	CA 27	44	170 E	-1.97	-0.8
11/78	CA 26	34	150 W	-1.87	-0.8
11/78	CA 28	40	140 W	-2.17	-1.0
11/78	CA 29	48	170 W	-0.94#	> 0
10/79	WA 32	48	150 W	2.01	1.28
SPRING					
6/77	CA 7	43	170 E	-1.36	-0.2
6/77	CA 8	40	165 W	-0.82	-0.42
4/78	CA 16	38	165 W	-0.93#	-0.8
5/78	CA 17	34	140 W	-1.36#	-0.6
4/79	CA 32	34	150 W	-1.34#	-0.7

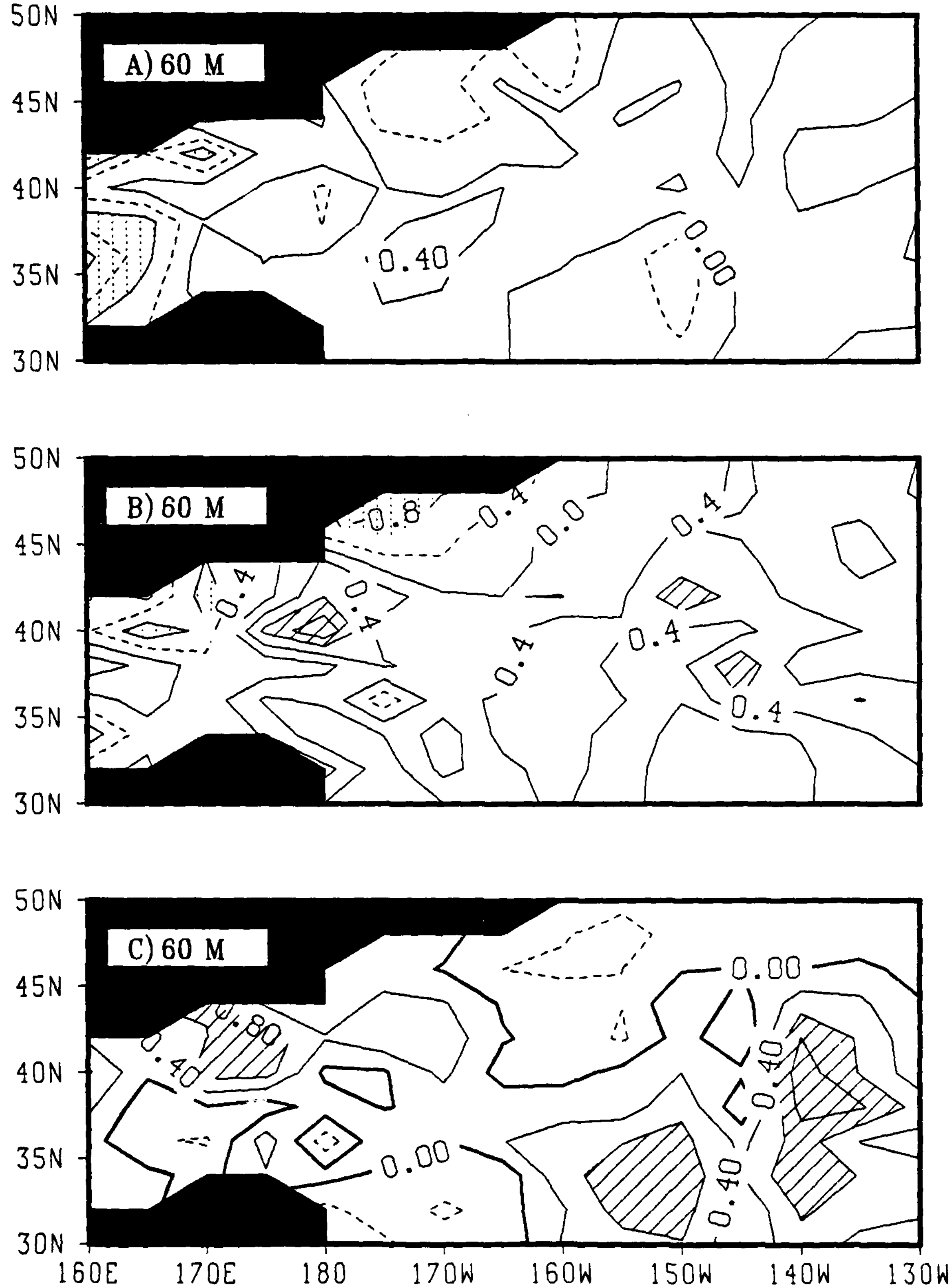


Fig. 19. Temperature anomaly at 60 m during (a) September, (b) October and (c) November 1977. The corresponding surface temperature anomaly is shown in Fig. 12.

The enhancement of the subsurface anomaly centers is particulary curious when there is a warm surface layer covering the region, as in this case. It appears that the 60 m level represents a buffer zone between the surface features and the deeper thermocline features. The mechanisms by which features in this zone are enhanced are not clear. One expects downward heat flux at the base of the mixed layer during the fall deepening period. This heat flux may be modulated by the vertical motions in the thermocline. It is possible that the wind stress imposed by the autumn storms may lead to the banded structure found at the 60 m level. The enhancement of the October 1977 cold anomaly at 60 m below the intense warm surface anomaly may be associated with the inhibiting of the normal downward heat flux. Consequently, the timing of the atmospheric forcing, the initial ocean thermal structure and the vertical motions on the thermocline may all play a role in explaining these subsurface anomalies. The ocean prediction model should be a useful tool in sorting out the relative importance of each mechanism.

7. Uncovering subsurface anomalies

Some of the cases discussed in the section on enhancement of subsurface anomalies would also fall into this category. In this section we discuss cases that are characterized more by the appearance of a surface or 60 m signature of an existing subsurface feature. Although the subsurface feature may be locally enhanced, the evolution here is more concerned with the emergence of a warm or cold anomaly due to uncovering the subsurface feature. A list of cases is provided in Table 5.

An example in this category is seen in the weak surface center (WA 4) at 38 N, 180 during September 1976 (Fig. 3d). As can be seen in Fig. 3c, this entire area was generally cold at the surface during August 1976. The emergence of the warm surface center during September is a reflection of an

Table 5. Cases of anomaly centers being revealed by the removal of a surface layer. The temperature anomalies are generally the surface values, except when indicated by a # symbol. Each of the case numbers with an asterisk is discussed in the text.

COLD ANOMALIES

Number	Month	Lat.	Long.	Temperature Anomaly (C) This Month	Temperature Anomaly (C) Prior Month
8	6/77	34	170 W	-0.79	0.3
21	7/78	42	175 E	-2.06#	-0.4
31	1/79	42	170 W	-0.37#	0.1
39	12/79	34	170 W	-1.18	0.4
WARM ANOMALIES					
4*	9/76	38	180	0.62	-1.5
5	7/76	42	175 E	2.18#	1.5
8	4/77	44	170 W	0.38	-0.2
35	11/79	36	180	1.27	-0.2

intense (1.87 C at 60 m) subsurface feature. However, the feature does not persist, as the surface signature is eliminated during October 1976 (Fig. 3e). A cold anomaly center (-1.0 C) appears at 60 m near 36 N, 180 during October, although the remains of a warm center are still found at greater depths (not shown).

It seems likely that this category of anomaly is the most complex. Although the uncovering of the subsurface feature is a surface-based process, the strength of the feature is dependent on initial conditions and internal ocean processes. The cold anomalies in Table 5 tend to emerge within a warm surface layer, and vice versa. Although many of these features are relatively weak, the vertical temperature structure is quite different in these locations. Their correct prediction will be dependent on accurate initial conditions, accurate representation of the internal ocean processes, and surface-based mixing processes.

8. Conclusions

The North Pacific Experiment TRANSPAC data set (White and Bernstein, 1979) represents a unique description of upper ocean thermal structure evolution over an extensive area. In this study, we have examined the development, maintenance and elimination of anomalies during January 1976 through December 1979 in a domain bounded by 30 N, 50 N, 130 W and 160 E. The 2 deg lat by 5 deg long resolution is only adequate to resolve relatively large scale anomalies. There is evidence that energetic smaller horizontal scale oceanic features west of the dateline and east of 140 W are not well-resolved by the observations or by the analysis grid. This is particularly true for the thermocline circulations described by White (1982) using a higher resolution grid. These small features will be aliased in the analyses used in this study. Another limitation of the analyses is that only monthly maps are available.

The definition of a significant anomaly is unfortunately rather subjective because of the data coverage and the spatial-temporal resolution of the analysis scheme. It is necessary to consider the anomalies relative to the mean monthly temperature for this four-year sample, rather than from earlier mean fields prepared by a different analysis procedure that utilized historical data (e.g. Barnett and Ott, 1976). There are considerable differences in the mean fields because this four-year period included two anomalous winters (White and Bernstein, 1979). As additional years are added to the sample, one may expect more stable estimates of the mean fields. However, the focus in this study is the month-to-month evolution of the departures from these mean fields.

A summary of the significant cold and warm anomalies is provided in Fig. 2. The longitudinal distribution of the anomaly locations is consistent generally with the seasonal fields of temperature standard deviations. That is, the primary generation regions are around 170 E and about 145 W, and there is a secondary maximum near 170 W. Perhaps more importantly, the time evolutions of the anomaly intensity are quite varied. The anomalies are frequently at maximum intensity during the first month they are detected, although the maximum intensity may also be reached during the month prior to their disappearance. Anomalies (whether warm or cold) form in all seasons, and may persist for periods of up to a year. The atmospheric forcing and internal ocean processes that lead to these varied evolutions are challenging research topics for ocean prediction groups. Selected case studies of particularly interesting warm and cold anomalies are described in detail in the text. The enhancement of subsurface anomalies appears to occur during each fall, and there are many cases of uncovering of subsurface anomalies due to changing surface conditions.

In summary, the TRANSPAC data set provides a variety of cases suitable for testing ocean prediction models. Understanding the physical processes involved in creating, sustaining and removing such anomalous conditions is necessary if we are to provide accurate predictions of the oceanic environment.

Acknowledgments. This study was made possible by the efforts of Warren White and Robert Bernstein who organized the TRANSPAC project and developed the objective analysis scheme. Steve Pazan of NORPAX provided us the data tapes, and Pat Gallacher of NPS assisted in the extraction of the analysis. Kevin Rabe and Dale Leipper of Compass Data System prepared the mean and anomaly charts as a part of a project with Bob Haney under Office of Naval Research funding (Contract N0001482 WR20022). Figure 2 was prepared by Miss Kyong Lee and the remainder of the computer graphics was done by Pat Gallacher, who devised the shading routine. Comments provided by Bob Haney, Pat Gallacher and Arlene Bird improved the manuscript, which was typed by Ms. Marion Marks and Miss Kyong Lee. This study was supported by the Naval Ocean Research and Development Activity, NSTL Station, MS under Program Element 62759N.

REFERENCES

Barnett, T. P., and J. D. Ott, 1976: Average features of the subsurface thermal field in the Central Pacific. Scripps Institution of Oceanography Reference Series 76-20, 13 pp plus figures and tables.

Elsberry, R. L., P. C. Gallacher, and R. W. Garwood, Jr., 1979: One-dimensional model predictions of ocean temperature anomalies during fall 1976. Naval Postgraduate School Tech. Rep. NPS 6379-003, 30 pp.

Elsberry, R. L., and R. W. Garwood, Jr., 1981: Numerical ocean prediction models, Goal for the 1980's. Bull. Amer. Meteorol. Soc., 61, 1556-1566.

Haney, R. L., 1980: A numerical case study of the development of large-scale thermal anomalies in the central North Pacific Ocean. J. Phys. Oceanogr., 10, 541-556.

White, W. B., 1982: Traveling wave-like mesoscale perturbations in the North Pacific current. J. Phys. Oceanogr., 12, 231-243.

_____, and R. Bernstein, 1979: Design of an oceanographic network in the mid-latitude North Pacific. J. Phys. Oceanogr., 9, 592-606.

_____, R. Bernstein, G. McNally, S. Pazan and R. Dickson, 1980: The thermocline response to transient atmospheric forcing in the interior North Pacific 1976-78. J. Phys. Oceanogr., 10, 372-384.

Appendix A

A list of new cold anomalies during January 1976-December 1979 is given in Table 2. The CA 1, CA 7 and CA 12 cases were discussed in the text. In this Appendix we present a short description of the remainder of the cold anomalies. A summary of the primary features and the likelihood that a mixed layer model will be able to predict these features is also provided for each case.

CA 2 An extensive cold anomaly develops during July 76 between 38-48N from about the dateline to the eastern boundary. Although not as intense as CA 1 in the west-central Pacific (only < 1.2 °C), this is again a dramatic change from the January to June conditions. For example at 42N, 160W the change is from +1.2 to -1.2 °C at the surface. It should also be noticed that these changes occur above 60 m, which remains warm except north of 44N, and east of 165W. The cold anomaly center at 46N, 140W extends to 300 m. During August 1976 the anomaly takes on a north-south character along 140W from 30N to 50N. Central values are below -1.5 °C at this time. This north-south orientation is associated with the elimination of the cold anomaly at 42N between 155-160W during July. By August 1976 the entire region is a weak warm anomaly. The penetration of the cold anomaly is to 60 m at 48N, 150W during August. Some evidence of a weak cold anomaly is also found at 120 m in the extreme northwestern corners of the grid, however this area remains warm at 200 m.

Although surface temperatures in the entire region north of 45N remain below normal during September, the anomaly is much weaker than in the preceding two months. The southern branch near 34N, 140W remains during September 1976 at the surface only. This center is greatly expanded toward the west during October 1976. There is no evidence of a cold anomaly at 60 m at this time. This anomaly also fades during November 1976.

Summary: This anomaly, or perhaps a series of anomalies, is an example of a complex deformation from an east-west to north-south orientation and then a division into a southern center which persists longer than the northern center. These shape changes are due to the introduction of weak warm anomalies within and adjacent to the cold anomalies. Because most of the changes are concentrated near the surface, they should be predicted by the mixed layer model.

CA 3 This anomaly (-1.0 °C) appears during October 1976 only on the 60 m level at 36N, 180. Below this level there are weak warm anomalies and at the surface there is only a weak cold anomaly. The most noteworthy feature of this anomaly is the change at 60 m from being in the southern portion of warm anomaly WA 4 to being a cold anomaly. The cold anomaly appears short-lived, unless it becomes the central feature (-0.6 °C) of a generally cold region at 60 m along 38N during December 1976.

Summary: Although this is not a major anomaly in terms of either intensity or areal extent, the large change from a warm to a cold anomaly may be indicative of an anomalously deep penetration of a surface feature.

CA 4 A small, strong cold anomaly is found during December 1976 at 34N, 165E between 120 m (-1.44 °C) and 300 m. There is also a cold center between the surface and 60 m, although this center is 4 deg. lat. to the north. This near-surface center could also be considered to be the remnants of the

southern branch of CA 1 on the October and November maps. The subsurface portion appears in the November 1976 map, but has almost disappeared by January 1977.

Summary: This is an ambiguous case with a surface anomaly which may or may not be attached to a subsurface (clearly advective type) anomaly. There is some question as to the ability of the analysis scheme to position and define the magnitude of these anomalies. Is the accuracy ± 2 lat and ± 5 latitude? How are these positions and intensities affected by data density during subsequent months?

CA 5 An extensive cold region developed throughout the central region during January 1977. The minimum T value (-.99 ^{o}C) was at 44N, 170W, although there were also two centers along 38N at 160W and 180. These three centers are also found at 60 m and perhaps are reflected in the generally high T that have persisted at 120 m since January 1976. Although the northern branch of this CA is eliminated at the surface during February 1976, the 60 m value remains. A weak center in the region of the northern CA re-appears during March 1976 and then disappears again in April 1976. The southern branch is amalgamated into a large scale CA that develops during February 1976. A general CA continues at the surface and 120 m in the southern region through April 1977. A warm anomaly at the surface covers this weak anomaly during May 1978. However, below-normal temperatures re-appear at the surface and 60 m during June 1977, although this may be more due to a deep CA (to 200 m) during this month.

Summary: The development and evolution of this anomaly is evidently related to the surface-based processes. Both the development and the subsequent modifications in the northern and southern branches should be predicted, except perhaps for the changes noted in June 1977.

CA 6 This feature is similar to CA 5. It develops in January 1977 with a minimum (-.96 C) at the surface near 38N, 170E. There is some reflection as deep as 120 m into a region of general WA at depth. This feature is amalgamated into a larger CA that develops between this anomaly and CA 5 during February 1977.

Summary: Similar to CA 5 except the blending with the new CA during February 1977 makes this feature rather short-lived.

CA 8 A comparatively minor transition from generally warm to generally cold occurs from May to June 1977. The shallow warm surface layer is probably eliminated, which exposes cooler water established in January and February 1977. The center at 34N, 170W is relatively weak (-.79 ^{o}C). The exact location is not as important as the broad area of lower than normal temperature throughout most of the domain. The subsurface anomaly extends to at least 200 m. There is little history associated with this feature except a small CA at 38N, 165W during May 1977. Furthermore the subsurface feature almost completely disappears during July 1977. A CA center at about 43N, 170E is much intensified (-1.36, -1.43, -1.12 and -.50 ^{o}C at 60, 120, 200 and 300 m respectively) compared to previous months. This is in the general region of the major CA 7 formed during February 1977, but this feature had appeared to weaken considerably in the intervening months. It is also interesting that this intense surface feature has a slight warm anomaly at the surface.

Summary: The elimination of the warm surface anomaly is probably related to anomalous atmospheric forcing during the month and should be predicted. The subsurface intensification is not likely to be well predicted; nor is the rejuvenation of CA 7 likely to be well predicted.

CA 9 This July 1977 anomaly may have its roots in a weakly stratified region associated with the major CA developed in February 1977 in this same region. Although the more intense (-1.92 ^{o}C) surface center is located at 36N, 175E, the weaker surface center near 44N, 175E has more indication of a cold anomaly at 60 and 120 m. At 200 and 300 m the more intense CA center is at 40N, 175E, which is the same location as the CA centers during April and May 1977. A subsuface CA center remains in this general location for the remainder of 1977 and into 1978. However the surface signature is removed during August 1977.

Summary: This prediction should show the sensitivity to the initial weak stratification that existed due to earlier CA in this region.

CA 10 A weak CA develops at about 47N, 150W during July 1977. Perhaps the most suggestive aspect of this anomaly is the southwest-northeast orientation between this anomaly and CA 9. It suggests an anomalous storm track during July 1977. This anomaly is neither deep nor persistent as the northern portion is nearly gone and the southern part is merged with an extensive CA during August 1977.

Summary: This case may provide an example of anomalous upper ocean condition along a SW-NE track due both to anomalous atmospheric forcing and favorable stratification in the ocean.

CA 11 A major (+1.82 ^{o}C) cold anomaly develops during August 1977 at 40N, 165W. This anomaly occupies the central one-third of the domain. As is the case with the adjacent WA 12 and WA 15, this feature does not penetrate to 60 m. During the previous month, there was a relatively weak CA in the central area between CA 9 and CA 10. The development of CA 11 supersedes these two CA's. In the following month the CA is greatly weakened, although a minimum temperature is maintained within the inverted u-shape formed by WA 12, WA 13 and WA 15.

Summary: The development of a major CA between two major WA is clearly an important prediction problem. The atmospheric conditions leading to this strong pattern during the summer are clearly of much interest. It is expected that the mixed layer model will predict these developments quite well.

CA 13 A general region of below-normal T in the southwest quadrant appears to be intensified at all depths during November 1977. The primary surface signature occurs at 36N, 180, above an intense center at all depths (-1.96, -1.74 and -1.41 ^{o}C and 120, 200 and 300 m respectively). This subsurface center develops within a generally cold region that has persisted in the southwest quadrant since February 1977. During December 1977 this center is disrupted by the appearance of a weak WA at 38N, 180, at 120 m and below. During January 1978 this WA disappears and there is again a general region of below-normal temperatures. This CA is further intensified at all depths during February 1978, although it is subsequently diminished during March and April 1978.

Summary: This is a good example of enhancement of deep cold anomalies during the fall. The appearance of the WA during December 1977 suggests a problem of horizontal resolution or a quirk of data coverage between months. This anomaly and CA 14 are similar in development within a general region. During subsequent months the different centers dominate, which again may be a problem of horizontal resolution or data coverage. Because the surface signature is not a very important aspect of this CA during November and December, it is unlikely the mixed layer model will predict the evolution very well. During February and March 1978 the surface signature appears to be more dominant and the mixed layer model should yield a better prediction.

CA 14 This anomaly at 34N, 170E during November 1977 is similar to, but weaker than, CA 13. It becomes the dominate center during December 1977, but is again weaker than CA 13 during January 1978. However, during February 1978 this anomaly is again the stronger of the two centers. After diminishing during March 1978, there is again a center at all depths in this region during April 1978. Although a WA at the southwest edge of the grid seems to eliminate this anomaly during May 1978, there is again a CA at 34N, 165E between 60 m and 300 m during June 1978.

Summary: Similar to CA 13, and indicates fluctuations in intensity of a deep thermocline feature from month-to-month. It is doubtful whether the mixed layer model will be able to predict the subsurface intensity changes.

CA 15 A third (along with CA 13 and CA 14) anomaly center is present at 40N, 175E during January 1978. This anomaly also extends to 300 m. During February 1978 the anomaly center weakens, although the minimum T is less than -1.0 °C. An intensification and increase in size occurs during March 1978, with the center at 40N, 170E. The intensity then diminishes again during April 1978. However the feature is evident, especially below 60 m, during May 1978 and June 1978.

Summary: It is perhaps misleading to identify three separate centers within the generally cold western region during late 1977 through June 1978, especially when the lobes of CA 12 were not similarly separated. The primary difference is that these three centers can be identified with individual deep thermocline features which appear separately, and which alternately intensify and weaken. By contrast the lobes of CA 12 appear to be manifestations of shifts in the atmospheric forcing. The subsurface features of CA 12 do not appear to be a significant aspect of the surface center location or intensity. Thus these seem to be separate prediction problems.

CA 16 A moderate intensity (-93 °C at 120 m) anomaly appears below CA 12 during April 1978 at 38N, 165W. This feature extends to 300 m (-.51 °C). The location is within a general field of below-normal temperatures during the previous month. The region remains cold during May 1978 as well, but one can no longer identify a center.

Summary: This is a relatively minor feature compared to the evolution of CA 12 above. The interest lies in whether the mixed layer model will indicate any of the enhancement of the deep cold anomaly. It should be noted again that the time resolution is really not adequate to describe this feature, which appears to exist for only a month.

CA 17 A moderate intensity (-1.36 °C at 200 m) feature occurs during May 1978. The center is at 34N, 140W. This is below a generally cold region at 60 m that is associated with CA 12. There is no surface signature. During June 1978 the feature has disappeared at 200 and 300 m. The center at 120 m is quite weak (-.56 °C) and might be associated with the remnants of CA 12 rather than this anomaly.

Summary: Because this anomaly appears only at depth, the mixed layer model is unlikely to predict its development or its rapid decay. The number of observations available to define this feature may be marginal because of its location in the southeast corner of the domain.

CA 18 The intense (-2.07 °C at surface) center develops at 38N, 175E during May 1978. It is located within an east-west band of anomaly centers that also includes CA 15, CA 16 and CA 12. At 60 m and below the anomaly is merged with CA 15 during May. However the two centers are split by a warm intrusion during June 1978. The surface signature of CA 18 is stronger than CA 15 during this month. Likewise the subsurface centers of CA 18 are also more intense than CA 15. This aspect continues during July 1978, when the remnants of both are covered. During July 1978, the central value at 60 m is -2.06 °C. Nevertheless the feature either disappears or splits off as another center (called CA 21 below) during August 1978.

Summary: It is not likely that the development and evolution of this anomaly as a separate feature will be predicted by the mixed layer model. Rather it seems that thermocline processes are primarily responsible. One must also determine if the data density is adequate to distinguish between the individual centers (especially CA 15 and CA 18, and later CA 21).

CA 19 A moderate intensity (-1.03 °C at 60 m) appears during July 1978 at 44N, 155W. This anomaly is located under WA 25 at the surface. The anomaly forms within the generally cold area that existed as part of CA 12. During August 1978 the intensity increases at 120 m and 200 m. Some weakening occurs during September 1978. There is little evidence of the anomaly below 60 m during October 1978, and the center at 60 m is absorbed in a broad band of below-normal temperatures.

Summary: Because of the time resolution of the data, one can not determine if CA 19 was intensified early in the month and then WA 25 covered the cold anomaly. The alternative explanation would be an enhancement due to thermocline processes, which would not be well-predicted by a mixed layer model.

CA 20 This moderately intense (-1.45 °C) forms at the surface near 46N, 165W during July 1978. The center is made distinct from CA 12 by the formation of WA 25. At 60 m there is warm water. During August and September 1928 there is a gradually weakening of the anomaly along the northern boundary.

Summary: Although this anomaly may have formed by the northwestward extension of CA 12, it seems likely that the distribution of atmospheric forcing produced both CA 20 and WA 25. The mixed layer model should provide a description of the evolution and the associated atmospheric systems.

CA 21 A deep and well-defined anomaly forms during July 1978 at 42N, 175E. It appears that this feature is separate from CA 18 which existed during May and June 1978. However, the displacement is only 5° long to the east, so the separate existence might be questioned. The anomaly has no surface signature during August 1978, and is considerably weakened at all subsurface depths.

Summary: The origin of this anomaly is rather uncertain. Because it appears within a generally cold region and is near the western edge, it is likely that the development is related to thermocline processes. However, this may also be an example of uncovering a cold anomaly by removal of a layer of warm surface water. If the latter is true, the mixed layer model may reveal some of the surface signature changes.

CA 22 An anomaly center along the northern edge at 150W during August 1978 is the central feature associated with the replacement of WA 24 with a generally cold regime. The cold region at the surface persists through September 1978, when the anomaly appears to extend to 60 m. This is unusual for a summer anomaly, but is probably a result of the persistent cold temperatures in this region except for the month of July. A weak surface center is found during October 1978, but the appearance of WA 27 during November 1978 marks the end of the surface signature. At 60 m there continues to be a cold anomaly through November 1978.

Summary: This feature should be well-predicted by the mixed layer model. A key aspect is the depth of penetration during September 1978 since it appears that the near-surface layer of warm water is eliminated during this month.

CA 23 Intensification of a cold anomaly occurs between 60 m (+1.8 $^{\circ}$C) and 200 m during September 1978. No surface signature appears directly above 36N, 180 although there is a weak (-.21 $^{\circ}$C) center two deg lat to the north. The anomaly intensifies within a general region of below-normal temperatures that has persisted throughout 1978. The cold anomaly at 60 m is replaced by a warm anomaly during October 1978 and this disrupts the cold anomaly pattern at greater depths. By November 1978 the entire feature has disappeared.

Summary: The rapid amplification and equally rapid decay of this feature appears to be related to thermocline processes. Thus, it is unlikely that the mixed layer model will be able to predict the evolution.

CA 24 A somewhat suspicious cold anomaly appears in the southeast corner during September 1978. Values below -1.0 $^{\circ}$C are analyzed at the surface and 60 m but these are clearly not the central values, as the anomaly is evidently centered off the map.

Summary: There are inadequate data to define or predict this feature.

CA 25 What appears to be a moderately strong anomaly appears at 60 m during October 1978. A central value of -1.71 $^{\circ}$C occurs at 32N, 170W. Although the region was weakly below-normal during the previous month, there is little support for such an extreme value. The feature at 60 m almost completely disappears during November 1978. During November there is a surface signature of -.74 $^{\circ}$C at 32N, 175W, but this may be related to the cold surface anomaly center at 34N, 180 during October 1978.

Summary: This feature is rather suspicious. It seems likely that it is a result of data coverage along the southern edge.

CA 26 A strong (-1.87 °C) cold anomaly appears at 60 m during November 1978 at 34N, 150W. This location is under a warm anomaly at the surface and was only slightly below normal temperature during the previous month. However there was a rather well-defined center at 36N, 150W and 60 m during each of the preceding two months. There is also a weak (-0.69 °C) center at 120 m about 5 deg long to the east during October 1978. Both of the two centers at 120 m are apparent during November and December. A general region of below-normal temperatures at 120 m continues into January 1979, with small weak centers during February and March 1979. At 60 m during December 1978 the anomaly pattern is more related to the surface WA 27. However, during January through March 1979 the surface and 60 m patterns appear to be related to the cold subsurface anomaly.

Summary: Much of the evolution of this feature is apparently due to thermocline processes along 34N. However, the enhancement of the 60 m center during November 1978 and the covering and uncovering of the subsurface feature during subsequent months should be predicted by the mixed layer model.

CA 27 A relatively strong (-1.9 °C) center at 60 m is present at 44N, 170E during October 1978. At the surface there is a weak warm anomaly whereas at 120 m there is a -.88 °C center. This general region has been cold throughout most of 1978. During November 1978 the surface signature (-.82 °C at 40N, 170E) appears and the minimum 60 m temperature (-1.45 °C) is at 40N, 175E. Anomaly centers are now found at all levels (-1.01 °C at 300 m). The feature remains well defined at all levels during December 1978. However a warm anomaly appears at the surface and 60 m during January 1979, when the anomaly shrinks to a single point (44N, 170E) at 60 m and 120 m. During February 1979 the anomaly center continues at 200 m and reappears at 300 m.

Summary: This is an example of a subsurface anomaly that is enhanced as the surface warm anomaly is removed. The uncovering of the anomaly should be predicted by the model, but the enhancement of the deep anomaly may not be predicted.

CA 28 An extreme (-2.17 °C at 40N, 140W) center appears at 60 m during November 1978. This center is below an extensive WA 27 at the surface. There are anomaly centers at all depths to 300 m. A precursor of this anomaly exists at 60 and 120 m during the previous month. The decay of the system is very rapid as there is only a very weak indication of the center at 60 m and 120 m only during December 1978.

Summary: Although this is certainly a case of an enhanced subsurface anomaly, the primary mechanism appears to be due to thermocline processes. Consequently the mixed layer processes are unlikely to play a significant role in this event. The problem of adequate time resolution is also significant in this case because of the rapid appearance and disappearance.

CA 29 This feature includes two separate subsurface centers (48N, 170W; 42N, 175W) which have a similar origin during November 1978. The two centers evolved from a broad cold anomaly at 60 m during the previous month. The northern center is particularly enhanced at 120 m and is also the stronger of

the two at 200 m. The two centers almost disappear at 60 m during December 1978 as the surface features deepen. However, at 120 m and below, there is an enhancement and the two centers are connected. This trend continues during January 1979 although the 120 m is contained within a narrow east-west oriented band. However the 200 and 300 m centers (-1.02 °C and -.84 °C) have increased in strength.

Summary: Although these centers are relatively minor, the evolution of the subsurface anomalies below a warm surface layer occurs frequently enough that the problem should be studied. It is unclear what role the mixed layer processes play in this case as most of the event appears to be more related to thermocline processes.

CA 30 A narrow, east-west oriented band (near 46N, 140W) of cold water appears at 60 m during January 1979. There is only very weak surface signature in view of the presence of WA 27 to the southwest of this location. This feature is quite weak at 60 m during February 1979 and has disappeared in March 1979.

Summary: This is a minor feature which is of interest because of the existence of narrow east-west oriented bands of warm and cold water at depth during February and March 1979.

CA 31 Another narrow band oriented east-west along 42N appears between 60 m and 300 m during January 1979. The minimum temperature at 200 m (-1.02 °C) and at 300 m (-.84 °C) are found at 175W. The surface signature appears to be a relative minimum between WA 28 to the south and WA 29 to the north. The band continues during February and March 1979 although the 300 m center is missing during February. The surface signature during these months is a weak cold anomaly between the two adjacent warm anomalies. Further weakening occurs at all levels during April 1979.

Summary: Although this is primarily a thermocline-related feature, the mixed layer model may predict the surface signature given the initial deep temperature profiles.

CA 32 A double-centered cold anomaly appears between 38 and 40N and between 140W and 150W during February 1979. At 120 m and below the western center is more intense, whereas at the surface and 60 m there is little indication of the western center. The eastern center appears to be related to a cold anomaly that was just off the eastern edge during January 1979. This part of the feature disappears during March 1979. The western part appears to exist during March 1979 but the pattern is not very coherent in the horizontal or the vertical. During April 1979 the remnants of CA 26 and CA 32 appear to have merged at 34N, 150W. At this time the maximum deviation (-1.34 °C) is at 120 m and the intensity diminishes toward the surface and with depth (-.56 °C at 300 m). What little remains of this feature during May 1979 is closer to the original position of CA 32 (-.59 °C at 200 m near 40N, 145W).

Summary: This relatively minor feature appears to be a modulation of thermocline-related processes that will not be predicted by a mixed layer model.

CA 33 A moderate (-1.13 ^{o}C at 34N, 165W) anomaly is found at the surface only during June 1979. Another center is found near 38N, 150W during July 1979, when there is a distinct southwest-northeast orientation of the surface anomaly pattern. However this pattern is eliminated during August 1979 when almost the entire surface layer has above-normal temperatures, and the orientation is primarily east-west.

Summary: The development of an extensive but shallow cold anomaly during the middle of summer should be predictable with a mixed layer model.

CA 34 A southwest-northeast oriented cold anomaly also occurs between 60 and 300 m during July 1979. However, this feature is displaced about 10-15 deg long east of the surface CA 33. The maximum intensity (-1.01 ^{o}C near 32N, 155W) occurs at 120 m. During August 1979, only a trace of this anomaly occurs at 200 and 300 near 32N, 150W.

Summary: This feature is apparently related to thermocline processes that are not treated in a mixed layer model. The rapid appearance and disappearance of such an extensive cold anomaly is somewhat surprising. The data coverage during this period should be examined to learn more of the time scales involved.

CA 35 A very transient feature appears in the northeast corner during July 1979. The anomaly apparently extends to 300 m with maximum intensity at the surface (-1.06 ^{o}C) and at 200 m. Almost all evidence of this feature has vanished during August 1979.

Summary: Although the surface signature appears to be part of a northeast-southwest oriented pattern noted with CA 33, this feature also has a deep signature. Because of the highly transient nature, the data coverage in the northeast corner should be checked carefully.

CA 36 The month of September 1979 is marked by a rapid transition from high surface temperatures to below-normal temperatures over most of the domain. Of the two centers the western one at 40N, 170E is less intense (-.82 ^{o}C) and somewhat more transient. By October 1979, this feature has diminished in size and intensity. Only a southwest-northeast oriented freature remains, although it does extend to 60 m at this time. All traces of the feature have disappeared during November 1979.

Summary: Perhaps the most important aspect of this case is the dramatic change from warm to cold anomalies at the surface. A change of nearly 2 ^{o}C is involved. Because this change occurs during September, it is likely due to an enhanced atmospheric forcing. The mixed layer model may be expected to predict such rapid changes at the surface.

CA 37 As in the case of CA 36, a large scale transition from above- to below-normal temperatures occurs during September 1979. The larger and more intense (-2.01 ^{o}C) surface anomaly is found near 38N, 160W. This cold anomaly replaces a warm anomaly along the northern edge, but the lowest temperatures occur in the southern half of the domain. Although the surface temperatures were slightly above normal in this region during August, during the previous two months there had been a CA 33 in this region. There is even a -.62 ^{o}C at 60 m near 32N, 175W. Consequently it appears that this anomaly developed

preferentially in a region in which a thin, warm surface layer covered a cold subsurface region. Another interesting feature of this anomaly is the appearance of a broad, cold subsurface (between 60 and 300 m) region near 170W between 42-50N. There had been a cold anomaly at 200 and 300 m in this area two months earlier (July), but the transient centers associated with WA 34 had obscured the anomaly during the prior month. It is somewhat misleading that there is so little surface signature above this region. However, this was also the region of highest temperatures (WA 35) during the previous month. Consequently, the atmospheric forcing is presumably just strong enough to bring the surface temperature back to normal. But during October 1979 this northern area becomes the lowest temperature area (-1.51 °C at 44N, 170W). The surprising aspect during this month is that the 60 m temperature is above normal between the cold surface and subsurface layers. This may be related to downward heat flux within a thin layer below the mixed layer depth. During November 1979, the anomaly decreases in horizontal area and intensity (-.68 °C at 44N, 175W). However, now the anomaly is coherent to 300 m and the maximum intensity is at 60 m (-1.15 °C).

Summary: The rapid transition and extreme values attained in this case make it one which the mixed layer model should predict well. A particularly interesting aspect is the effects of the initial ocean temperature conditions-specifically the stability of the near-surface waters in WA 35 and in the sub-surface water near the southern and northern edges. It may also be that the apparent separation between CA 37 and CA 36 is due to differences in initial conditions, because the scale of the atmospheric forcing must be quite large in this case.

CA 38 An extensive cold anomaly develops during November 1979 in the eastern region (-.96 °C near 42N, 140W). The northern portion of the anomaly has not penetrated to 60 m at this time, whereas the southern portion has associated subsurface features near 36N, 155W and 38N, 140W. During December 1979 the anomaly penetrates through 60 m with several secondary minima. Consequently the eastern half of the domain generally has below-normal temperatures at all depths except 120 m. It is of interest that the area along 150W at 120 m was below normal in November and then is above normal during December. This may be a reflection of entrainment mixing near the base of the layer.

Summary: The development of the cold anomaly should be well predicted by the mixed layer model. Again the interesting aspect is the effect of the pre-existing, complex subsurface conditions in producing the secondary maxima/minima within the generally cold regime.

CA 39 A moderate (-1.44 °C at 60 m near 34N, 170W) center appears during December 1979 in a narrow band extending westward from the general region of CA 39. This feature appears to be related to a deep anomaly along this latitude band. The subsequent evolution can not be determined as this is the last map in the series.

Summary: The development of such a narrow and intense feature is of some interest. Although the narrowness is probably due to the ocean conditions (notice 60 m center at same location two months earlier), the atmospheric forcing conditions are also important. Given the proper initial conditions, the mixed layer model should provide a reasonable prediction.

Appendix B

A list of warm anomaly developments during January 1976-December 1979 is given in Table 3. The WA 12-16, WA 27 and WA 32 were discussed in the text. In this Appendix we present a short description of the remainder of the warm anomalies. A summary of the primary features and the likelihood that a mixed layer model will be able to predict these features is also provided for each case.

WA 1 The major anomaly during January-June 1976 is found in the southeast corner. This anomaly is present at the beginning of the series, and reaches maximum amplitude at the surface (2.02 °C at 34N, 150W) during February. During March through May 1976 the anomaly is progressively less intense at the surface. Either the western branch of this anomaly, or a new warm anomaly, develops at the surface near 36N, 160W in June 1976. However, the 60 m anomaly persists at about 34N, 150W throughout the period, although the intensity diminishes from 1.97 °C during March to 0.96 °C during June 1976. It is for this reason that the surface anomaly at 36N, 160W is likely to be a new surface-based anomaly.

The major warm anomaly is vertically stacked between the surface and 60 m from January-April 1976. Below this layer, there is a warm anomaly which diminishes in intensity, but is identifiable to at least 300 m. There appears to be a tilt toward the southeast with increasing depth, but the data may not be adequate to justify this inference. This warm anomaly can be identified at 120 m from January through July 1976. Maximum amplitude (1.24 °C) is reached during May 1976. At 200 m, the anomaly intensity is 0.61 °C during January 1976, seems to disappear during March 1976, and then re-appears during April 1976 with a value of .38 °C.

Summary: Given the initial values in January 1976, the mixed layer model should predict the intensification during February 1976, the decrease in intensity until April 1976 and then the surface transformation during May 1976 following the spring transition. The intensification at 60 m until March 1976, and the retention until July 1976, should also be predicted. The variations at 120 m and below are not likely to be due to surface-based processes and it is unlikely that diffusive processes will explain the diminution during February-March and the later increases.

WA 2 The second major warm anomaly during January-July 1976 appears to evolve from a small warm anomaly at 38N, 170E during January 1976. At this time the anomaly can be traced to at least 300 m, although the amplitude is less than 0.5 °C below 120 m. During February 1976 the surface anomaly extends east-west along 38N between 170E and 180. However, at 60 m and 120 m (and perhaps also below these levels) the warm anomaly at 38N appears to have amalgamated with a region of high temperatures along 42N. During March 1976, the anomaly assumes a north-south orientation along with separate centers at 42N and 38N. These centers appear to be vertically aligned to 120 m and then appear to be displaced about 5° longitude to the east at 200 and 300 m. Although this primary pattern during March 1976 is oriented north-south from the surface to 300 m, there continues to be an eastward extension of the warm anomaly along 42N at 60 m, 120 m and 200 m.

The northern center of the warm anomaly (42N, 170E) intensifies to 2.39 °C during April 1976. During May 1976, the center is found at 175E on the surface through 300 m maps. Another split seems to occur during June 1976 as two centers (44N, 180; 40N, 177E) appear at the surface. At 60 m and 120 m, the predominate center is at 40N, 180. The southern center of the warm anomaly on the March 1976 map diminishes in intensity during the following two-three months.

Summary: The primary prediction problem is to predict the change in shape and amalgamation of the anomalies with time and with depth. The change from February to March 1976 is particularly dramatic, and it will be especially interesting to see the relationship to internal ocean features or bottom topography in the region of 170E. It appears unlikely at this stage that surface-based processes have much of a role in this evolution.

WA 3 This warm anomaly developed near 35N, 160W during June 1976 as a part of an extensive region of high temperatures. During July 1976 the northern two lobes of this extensive warm anomaly are eliminated, leaving a warm center near 34N, 160W. This warm anomaly is distinct from the warm anomaly (WA 1) at 60 m and 120 m located at 34N, 150W, which has continued since January 1976.

Summary: The prediction problem is mainly centered on the formation (transformation) of WA 3 (and the other lobes) during June 1976, and the elimination of the northern part of the warm anomaly (and diminution of WA 3 itself) during July 1976 and the complete elimination of WA 3 during August.

WA 4 This anomaly appears at the surface during September 1976 as a weak (0.62 °C) warm center at 37N, 180. However, the anomaly is more intense below with values of 1.87 °C, 1.58 °C, 1.10 °C and 0.7 °C at 60, 120, 200 and 300 m. Consequently, this appears to be an intense, deep anomaly which has a weak signature at the surface because of the generally cold temperatures throughout the domain during September 1976. This anomaly is evidently not due to surface-based processes. Its evolution at 60 m from the August 1976 pattern is not clear. WA 3 seems to form between the two warm anomalies at 40N, 175W and 37N, 170E during August 1976.

WA 4 is eliminated at the surface on the October 1976 map, and is replaced at 60 m by a cold anomaly (-1.00 °C) at 36N, 180. At 120, 200 and 300 m on the October maps, there is a warm center at 38N, 175W which may be the remains of WA 4. During November 1976, a weak warm center located at 38N, 175W at 120, 200 and 300 m appears to be the end of WA 4.

Summary: The formation, translation and decay of this anomaly is dependent on internal ocean processes (perhaps related to bottom topography). Surface processes only play a role in obscuring the near-surface signature of the deep anomaly. The discontinuous displacement of the center may indicate that the 5° longitude resolution is inadequate to resolve the relatively small scale (about 10° longitude) feature.

WA 5 This anomaly observed during July 1976 is similar to WA 4 in the sense that there is a weak (0.56 °C) warm center (42N, 175E) within a generally low surface temperature field, although there is an intense (2.18 °C at 60 m) warm and deep anomaly below the surface. This warm subsurface anomaly forms in the general region of WA 2 on the June 1976 map, but the temperature maximum

during July 1976 is 5° longitude westward. As was the case for WA 4, the surface signature is eliminated (August 1976), while the subsurface is maintained. However, the subsurface center is again 5° longitude westward of the position on the previous month, and is amalgamated with a generally high temperature region along the western boundary during the subsequent month (September 1976). A separate center then reappears at 42N, 170E during October 1976 between 60 and 300 m, and disappears completely during November 1976.

Summary: Similar to WA 4.

WA 6 This anomaly develops during September 1976 at 60 m under generally cold surface temperatures. The area within the +0.5 °C isoline on the September 1976 map is roughly bounded by 177W and 160W, 40N and 49N. A similar area of high temperatures occurs on the 120 m map. At 200 and 300 m, the warm center is at 42N, 160W during September 1976. During October, the warm center at 60 m is more intense (1.84 °C versus 1.33 °C during September), which is also true at 120 m (1.09 °C versus 0.80 °C). At 200 and 300 m, the warm anomaly is now oriented east-west along 44N, as the southeastward extension observed in September 1976 has disappeared. By November 1976, the 60 m warm anomaly has been replaced by cold anomaly. The 120-300 m warm anomaly remains along 44N, with the predominate center at 175W. At the 120-300 m levels, the anomaly can be identified for another month (December 1976), although the center is now at 46N, 170W.

Summary: This evolution occurs under surface conditions of low temperatures. It does not appear to be a mixing phenomena because of the great depth extent, although the evolution at 60 m may be affected by surface-induced mixing. Certainly the disappearance of the anomaly at 60 m during November 1976 is an effect of mixing, and should be predicted.

WA 7 A north-south oriented anomaly develops during January 1977 along the eastern boundary. WA 7 is centered at 42N, 135W in January and at 40N, 135W in February, when the anomaly is generally located more south of center, in contrast to January when the higher temperatures appear farther north. However there may not be adequate ship observations in the northeast corner during the winter. The northern half of WA 7 disappears at the surface during March, as the center at 44N, 140W during April 1977 is probably a new development. The southern portion disappears during April 1977. A warm anomaly at 32N, 155W during April 1977 is just at the edge of the data coverage indicated in Fig. 2 of White (1982), and is probably not related to WA 7.

Summary: The development of warm anomaly along the eastern section has been predicted by Haney (1980). Its development has been associated with drought conditions along the west coast of the U.S. during this period. Thus it is an important feature to be predicted, especially because there are anomalously cold features developing farther west.

WA 8 This relatively minor anomaly appears at 44N, 170W on the surface map during April 1977, and is present to 300 m. At 200 and 300 m, the center is within a weakly warm region that has persisted for many months.

Summary: This feature will not be well predicted because of its small horizontal scale, and its origin appears to be related to thermocline processes, or to data density problems and decay.

WA 9 Another relatively minor anomaly appears at 44N, 140W during April 1977. Most of the northwest quadrant appears to be weakly warm at the surface and 60 m. At 60 m this may be due to WA 7. The surface signature of WA 9 disappears during May 1977.

Summary: Although this feature is weak and transient, its prediction is of some interest because of the horizontal scale. Because of the apparent relation to atmospheric forcing, it should be well-predicted by the mixed layer model.

WA 10 The edge of a significant anomaly appears in April 1077 at 30N, 160W from the surface to 200 m. The roots of this feature may occur as far back as January 1977. However, because this anomaly lies along the edge of the domain, and the ship tracks in Fig. 2 of White (1982) tend to be north of 32N, the feature is not well sampled. This WA also seems to be independent of WA 7.

Summary: This feature is not a good candidate for prediction studies because it lies on the edge of the domain. There are inadequate data for either initialization or verification.

WA 11 A broad and relatively weak anomaly develops at the surface during May 1977 in a region that has been generally cold since January 1977. The maximum T (+1.15 $^{\circ}$C at 38N, 175W) is also the surface signature of a deep WA (+.74 $^{\circ}$C at 300 m). It appears that the deep feature is separate from WA 8, which remains only as a secondary maximum at the surface. However, no other origin for the deep feature associated with WA 11 is evident. WA 11 disappears completely during June 1977.

Summary: The development of this feature is probably associated with the spring transition. Consequently the prediction of its occurrence, including its vertical depth and the subsequent disappearance is of some interest.

WA 12 A significant (+1.7 $^{\circ}$C) warm anomaly develops during July 1977 at 38N, 150W. The warm region extends over much of the southeast quadrant of the grid. The southwest-northeast orientation is partly due to a similar orientation of CA 9 and CA 11. During the following two months the orientation becomes more north-south, and the anomaly nearly disappears by October 1977.

Summary: This shallow anomaly should be well predicted as it is related to the atmospheric forcing.

WA 13 A minor surface WA develops during July 1977 at 48N, 170W. At this time, there is a CA at 60 m in this area. This anomaly is shifted westward during August 1977, although the exact displacement can not be determined because this anomaly is at the edge of the analysis domain. The merging of this anomaly with another WA to the SW is continued during September and October 1977. During this entire period, the WA does not penetrate to 60 m.

Summary: (Same as WA 12)

WA 14 A deep WA occurs at 36N, 135W between 60 m and 300 m during July 1977. Although the central values are about +.6 $^{\circ}$C at all depths, the warm area is quite large, especially below 120 m. Another 60 m WA center at 42N, 135W may be associated with WA 12 at the surface, although it is probably the

enhancement of a center at the same location during June 1977. The portion of the WA below 120 m is not found on the August 1977 map.

Summary: This feature will not be predicted by the mixed layer model. At first, the WA is similar to the mesoscale waves of White (1982). However, the spatial scales of the entire anomaly would seem to be too large.

WA 15 This extreme (+3.63 °C) surface anomaly develops during August 1977 at 42N, 170E (note that this is the edge of the grid so that the actual anomaly may be farther north). WA 15 completely replaces the surface signature of CA 9, although it does not penetrate to 60 m. The central value during September 1977 is diminished (+2.57 °C), although it is not clear that the entire anomaly is not being resolved on the present grid. During September, this anomaly and WA 13 are merged so that the entire northern edge of the domain is anomalously warm. In addition there is also a connection to WA 12 along the eastern side. Thus, there is an inverted u-shaped WA over the domain at the surface. The central part of the u-shape is the remnants of a cold anomaly that developed in August 1977.

Summary: Although this anomaly is clearly related to the atmospheric values, the extreme central values will provide a challenge for ocean prediction. Clearly the vertical profile of the anomaly will be a critical parameter in getting the correct surface temperature values.

WA 16 Although it is likely that the large-scale WA pattern existing in October 1977 is simply the combination of WA 12, WA 13 and WA 15, there are several interesting features on those maps. One of the maxima (+2.15 °C) is between and south of the previous WA 13 and WA 15 centers. There is also a small but deep WA below this center at 40N, 180. The second maxima (+1.59 °C) is between the prior WA 12 and WA 13 centers. Another interesting feature is the apparent intensification of 60 m WA and CA features. Not only are there more centers, each of the central values is larger than on the previous maps. The smaller horizontal scale of the 60 m anomaly centers is in part offset by their tendency to be organized in bands.

Summary: The modification of the surface Wa centers is likely to be well predicted by the mixed layer models. However, the physical processes occurring at the sub-MLD levels are not clear so that predicting correctly the 60 m field during October 1977 should be a significant challenge.

WA 17 The weak surface anomaly at 34N, 155W during November 1977 is the surface signature of a significant (1.27 °C) WA at 60 m and at 120 m (1.04 °C). The precedent conditions for this anomaly are not evident on the October map, except that there was a WA center at 40N, 160W at 60 m with a warm anomaly toward the southwest. There is also no indication of WA 17 on the December 1977 map.

Summary: This case appears to fall in the set of enhanced anomalies during the fall. Its rapid generation and decay make it a difficult case, because there is inadequate time resolution in the data to describe the evolution.

WA 18 Another weak surface signature during November 1977 is found at 34N, 140W. Below the surface there is an extensive north-south oriented WA that

extends at least to 300 m. Evidence for this subsurface anomaly along the eastern edge exists on the September 1977 map. During October the warm anomaly appears somewhat distorted. However, WA 18 is well-defined in two deep centers at 40N, 140W and 34N, 140W. The northern center is maintained during December 1977, although weakened by the cold anomaly that spreads over the eastern region during that month. Both of the anomaly centers have disappeared during January 1978.

Summary: Similar to WA 17, except the deep anomaly signature near the eastern edge makes this case difficult to treat, both in terms of analysis and of prediction.

WA 19 A weak anomaly at 38N, 135W interrupts a generally cold regime over the domain during December 1977. The maximum intensity (+.75 °C) is found at 120 m, and there is also a weakly warm region toward the south-southwest. These features disappear during February 1977.

Summary: This is a relatively minor feature that is clearly related to thermocline processes that will not be predicted by the mixed layer model.

WA 20 This feature at 34N between 155W and 160W appears during January 1978 only at 120 m and below (at 32N, 165W). Because of the weak signature below and the extreme east-west tilt between 120 and 200 m, it is not clear whether these features are related. The feature did not exist during December 1977 and has disappeared during February 1978.

Summary: A possible explanation for the center at 120 m is a downward heat flux due to entrainment mixing, which should be predicted by the mixed layer model. An alternate explanation is variations in data resolution during the period.

WA 21 A warm anomaly develops in the extreme northeast corner of the grid during March 1978. Between the surface and 120 m this center is a part of the generally high temperatures along the eastern boundary. At 200 and 300 m there is only a center in the northern region. There is some reason to question the analysis in the northeast corner because of the normal absence of shipping tracks during the late winter. The surface anomaly during April 1978 seems to be located east of the edge. A surface center reappears during May 1978 at 48N, 135W. This feature is weak (+.65 °C) at the surface and there is even less amplitude at 60 m.

Summary: Although the data problems in the area may raise questions about the analysis, the appearance of this surface warm center breaks an extended period of below normal temperature. Some fraction of this generally warm area should be predicted by the mixed layer model, although some of the anomaly is associated with a deep thermocline feature.

WA 22 This is the first warm anomaly in the central Pacific area after many months of below-normal temperatures. The anomaly (+1.02 °C at 36N, 180) appears only at the surface, and covers most of the southwest quadrant during June 1978. In the following month this anomaly is merged with a much stronger WA 23 to the northwest. No center is recognizable during August 1978.

Summary: This feature should be well-predicted by the mixed layer model as it appears related to the atmospheric forcing. Another interesting aspect of this development is its relation to the spring transition in this region. Prior to June 1978, this region had below-normal temperatures.

WA 23 An extreme (+2.85 °C at 40N, 170E) warm anomaly develops along the western edge during July 1978. An extensive area with greater than +2 °C exists, and this merges with WA 22 toward the southeast. Beneath the northern portion of this warm anomaly are found the remnants of CA 15 and CA 18. Thus some large vertical gradients exist between the surface and 60 m. During August 1978 the warm anomaly is primarily limited to the region between 160 and 170E. This warm area is replaced by a weak cold anomaly during September 1978.

Summary: Similar to WA 22.

WA 24 An unusual warm anomaly appears near 48N, 145W during July 1978. Its unusual features are its strength (1.35, 1.44, 1.24 and 0.92 °C at the surface, 120, 200 and 300 m respectively) and its sudden appearance and disappearance. The only precursor of above-normal temperatures during June 1978 are between 120 m (+.21 °C) and 300 m (+.25 °C). Only a weak center (+.36 °C at 120 m) exists between 60 and 120 m during August 1978.

Summary: Although the surface signature of this feature appears to be related to atmospheric forcing, there is no mechanism for penetrating such an intense warm anomaly to such great depths. The individual ship observations should be checked to describe better the evolution of this unusual event.

WA 25 A moderate (+1.21 °C at 40N, 155W) surface anomaly appears during July 1978. This location was near the center of CA 12 during June 1978, and the temperatures at 60 m remain below normal. (CA 19 is located 4 deg lat to the north and CA 12 is 4 deg lat to the south.) The surface anomaly expands in size and intensity through September 1978 (+1.97 °C at 40N, 165W). During October 1978, the feature decays significantly (+.78 °C at 40N, 155W).

Summary: The evolution of this feature should be well-predicted by the mixed layer model. An interesting feature is the presence of an extensive area of below-normal temperatures at 60 m during October 1978. This development may be a result of the lack of production and/or downward penetration of warm surface water to this depth as expected during the seasonal cycle.

WA 26 During October 1978 a double-centered (38N, 165E and 36N, 175E) feature appears. Although these small centers along the western boundary have not generally been included as anomalies, this case is slightly different. During November 1978 the western center at 120 m is very strong (2.22 °C) and the two centers form a band along 36N of warmer water at all depths. The feature decays during December 1978, but this band again appears to be warm during January 1979 and February 1979.

Summary: This feature is clearly related to the energetic thermocline processes along the western edge. The large depth and intensity of these processes leads to surface signatures that will not be well-predicted by the mixed layer model.

WA 27 An extensive surface anomaly develops over the eastern half of the domain during November 1978. The center (+1.74 °C at 42N, 145W) is well to the east of the remains of WA 25 in the previous month. The main core of the surface anomaly is sustained during December 1978. During this month it appears that parts of the anomaly have penetrated to 60 m, thus destroying most of the major cold anomalies (CA 26 and CA 28) that existed at that level during November 1978. The downward penetration results in a very chaotic pattern at 60 m during December 1978. In the following month the surface and 60 m centers are very similar. Cooler water has appeared to the north, east and south of the center at 42N, 150W. The center shrinks further in horizontal domain during February 1979, when it appears to have penetrated all the way to 300 m (+1.54 °C at 42N, 140W). However the more likely explanation is a superposition of the surface feature and a thermocline feature to the east.

Summary: The extensive area covered by this warm anomaly, and that it is the first above-normal temperature in this area during a generally cold year, makes this feature a significant event. Most of the evolution of the feature should be well-predicted by a mixed layer model, although the extreme vertical extension during the last month is likely due to thermocline processes.

WA 28 A narrow east-west oriented band of above-normal surface and 60 m temperatures is evident during December 1978. At the western end is located WA 26, and a moderate center (+1.23 °C) occurs at 34N, 170W. During January 1979 the east-west orientation remains, but the maximum temperatures at the surface and 60 m are at 36N, 180. There is also a downward penetration to 120 m during January. However, it is not clear whether this penetration is actually due to the superposition of a deep thermocline feature. This aspect is particularly noted during February 1979. At this time there is an extreme (+2.12 °C at 34N, 175E) center that extends through the entire depth. During March 1979 almost all of the deep southern portion of the anomaly disappears, and leaves only a weak band of above-normal temperatures.

Summary: It appears that several processes occur within an east-west band. The positioning of actual centers may be somewhat spurious because of the presence of the southern edge of the domain. It will be interesting to see if the mixed layer model can predict such a band. The extreme values during February 1979 are likely due to thermocline processes and the vertical extent will not be well-predicted.

WA 29 A warm anomaly forms at the surface and 60 m during January 1979 and persists for several months along the northern wall. Although there is not a well-defined center during January, this appears to be a separate feature from WA 27. The two centers are easily distinguished at 60 m during February 1979 when WA 29 was a +1.72 °C value at 46N, 165W. During this month the surface signature is quite weak. However, in March 1978 the surface signature again appears although the feature is somewhat weaker (.88 °C at 60 m). This may be in part due to a larger vertical extent as the feature appears also at 120 m during March. The surface to 120 m pattern is continued during April 1978 and somewhat into May 1978. During the latter two months the maximum surface temperatures are found along the northern edge. However, these values are regarded as being suspicious because they lie on the edge in a region where there is not likely to be good ship coverage.

Summary: Although this is a relatively minor feature, its persistence for a long time makes its prediction of some interest. The mixed layer model should be capable of describing its evolution. However, the effect of data density along the northern edge in defining this feature must be carefully examined.

WA 30 A small but deep center at 40N, 170E appears during February 1979 as a northward extension of WA 28. As the latter features diminish during March 1979, WA 30 continues (+1.05 °C at 120 m). The size of this feature is reduced to nearly a point value during April 1979. However, during May 1979 a very narrow elongated anomaly exists between the surface and 120 m. It appears from the 200 and 300 m maps that this shape is determined by the presence of two separate centers (40N, 165E and 42N, 175E). The maximum intensity of the features occurs during June 1978 (+1.84 °C at 60 m and 1.55 °C at 120 m). During July 1978 the feature breaks into smaller centers.

Summary: It is rather arbitrary to include this small center as an anomaly in the same sense as used in the remainder of this description. However it does attain a considerable horizontal extent during June 1979. It is expected that this feature is primarily a result of thermocline processes and will not be well resolved by a mixed layer model.

WA 31 A moderate (+1.23 °C at surface and +1.03 °C at 60 m) center is found near 37N, 170W during March 1979. The location of this center was in a lobe of WA 28 during February 1979. Consequently this may not be a new center, but an intensification of a pre-existing feature. During April 1979 the surface center disappears, but there is a well-defined (+0.91 °C at 120 m) center near 38N, 165W between 60 and 300 m. The subsurface center (again at 38N, 170W) is even more intense during May 1979 (+1.18 °C at 60 m and 1.15 °C at 120 m), and there is again a surface signature. During June 1979 the surface signature is eliminated by a cold anomaly and there is little coherence in the vertical between the 60-120 m and the 200-300 m patterns.

Summary: The intensification of the surface and 60 m centers during March 1979, and the appearance and disappearance of the surface signature, should be predicted by the mixed layer model. The subsequent development of the deep anomaly during April 1979 will not be predicted.

WA 32 Two surface centers exist during May 1979 within the generally warm northeast quadrant of the grid. The southern center (+.90 °C) at 42N, 155W is well within the expected ship tracks, whereas the second center is located on the boundary at 150W where there may not be adequate coverage. There were indications of two similar centers during April 1979. By June 1979 there is a broad area at 60 m with above-normal temperatures (+.95 °C at 44N, 160W). At the surface the pattern is more complex, although there is a +.93 °C center at 46N, 155W. There is a considerable intensification and spreading of the surface anomaly during July 1979, which might justify naming a new center. The central value at the surface is now 1.79 °C near 44N, 160W. The subsurface center is at 48N, 155W and has a value of 1.09 °C. During August 1979 the region expands toward the east and weakens at the surface, except for an apparent center off the northern edge of the grid at 150W. The August 60 m pattern remains rather similar to the July 1979. The September 60 m pattern is also similar, although there was a marked weakening of the surface pattern during this month. During October 1978 a cold anomaly covers the surface.

Concurrently there is a marked increase in the size and intensity (+2.01 ^{o}C near 48N, 150W) of the 60 m anomaly. Finally the 60 m anomaly is reduced considerably during November 1979, except for a western lobe (+2.07 ^{o}C at 48N, 170W) and a southern lobe (.88 ^{o}C at 42N, 150W). The western lobe appears very suspicious, although it does extend to 300 m and is present during December 1979.

Summary: There is a complex evolution in this long-lasting feature, or the superposition of two features if the July 1979 center represents a new event. Data and/or analysis questions arise relative to centers along the northern wall during April, May and August and the extreme values at 48N during November and December 1979. There are also interesting questions regarding the vertical coupling between the surface and 60 m. Especially interesting periods are those during June when the anomaly appears to be very deep and during October when there is a large increase in temperature at 60 m as the surface becomes cool. One would expect the mixed layer model to predict this vertical coupling if the entrainment mixing is the primary mechanism.

WA 33 During June 1979 one of the surface centers within the generally warm eastern area is found at 38N, 140W. Although there is not a significant anomaly at 60 m below the surface center, there is a branch extending southwestward that does have significant anomalies at both levels. During the following month the 60 m center is evidently displaced off the grid. The surface centers are less intense during July 1979. The surface anomalies associated with WA 32 and WA 33 are merged during August 1979, and there is a separate center at 38N, 135W. There continues to be no indication of downward penetration to 60 m during August. The WA 32 and WA 33 centers are separated, and the latter is along the eastern edge at 46N. Finally, the anomaly is mainly off the grid.

Summary: Most of this anomaly occurs in the corner of the grid. The modifications of the surface features should be predictable with the mixed layer model.

WA 34 A moderate (+1.3 ^{o}C) surface anomaly during July 1979 at 36N, 175E forms the lower left corner of an extensive region of above-normal temperatures extending diagonally across the grid to the WA 32 center. This anomaly appears to be the surface signature of a deep and intense (1.09 ^{o}C at 300 m) anomaly at 40N, 175E. The relationship of the deep anomaly to WA 30 which was at 40N, 170E during the previous month is not clear. It is possible that the weak cold anomaly that enters at 38N, 170E has caused a distortion in the warm anomaly. If so, the WA 34 and WA 30 may be the same feature. During August 1979 there is again a deep center at 40N, 175E. There is also a deep and intense (1.24 ^{o}C at 200 m) near 36N, 180. Further distortions in the pattern occur during September 1979 when the two subsurface centers are at 40N, 170E and at 42N, 180. During October 1979 the primary subsurface center is at 40N, 170E.

Summary: Except for the initial surface center, and the subsequent modifications of the surface pattern during August and September, it appears that little of the features associated with this anomaly will be predictable by a mixed layer model. It is of some interest to determine whether it is data

density problems or a characteristic of the objective analysis scheme to produce the "hopscotch" pattern of subsurface centers.

WA 35 The triangular-shaped warm anomaly that develops during November 1979 appears to be due to uncovering of a deep warm anomaly. The surface center at 36N, 180 is reflected at all depths. The extension toward the northwest from this location is also present at all depths. At the surface there is a connection between the primary center and a secondary center at 34N, 170E, which is also present to 300 m (1.19 °C). However there is an intermediate cold center between these two centers at all subsurface levels. During December 1979 the primary center at the surface shifts northwestward to 38N, 170W. There is an additional center (1.79 °C) at 44N, 170E. Both of these centers extend to 300 m.

Summary: This is a case of removing the surface layers and exposing an extensive and intense warm anomaly. The shifts in locations of these centers is guided by thermocline processes that are not represented in the mixed layer model.

WA 36 A subsurface anomaly appears at 34N, 140W during August 1979. There is some evidence of a weak warm anomaly at 32N, 140W during the prior month. By contrast, the anomaly is rather well developed at 60 m (+.99 °C) and at 120 m (+.95 °C) during August. By September 1979, there is still a +.96 °C center at 60 m near 34N, 145W, but the intensity falls off rapidly above and below this level. There is a warm surface anomaly at the southeast corner, but this feature appears spurious. During October 1979 there is a well-defined center at 34N, 135W that extends between the surface (+1.3 °C) and 120 m (+.82 °C). Small centers appear rather erratically at the surface and at depth during the next two months, but it is not clear whether they represent a continuation of this anomaly.

Summary: The development of this anomaly appears to be related to thermocline processes. Its location near the corner of the grid and its erratic behavior do not make it a good candidate for prediction.

WA 37 An extreme (+2.07 °C at 60 m) anomaly appears during November 1979 at 48N, 170W. The anomaly is quite intense at depth (1.1 °C at 200 m) although it does not have a surface signature, which is adjacent to CA 37. However, during December 1979 there is a surface signature (1.52 °C at 48N, 175W) and there continues to be a deep warm anomaly, although it has weakened at all depths. As this is the end of the map series, it is impossible to follow the evolution of this rather extreme event.

Summary: This anomaly develops at the edge of the grid during a season when one would not expect a lot of ship tracks this far north. If this feature is real, its existence and evolution appear to be related to subsurface processes that will not be predicted by a mixed layer model.

INITIAL DISTRIBUTION LIST

1.	Defense Technical Information Center Cameron Station Alexandria, Virginia	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3.	Commanding Officer (Attn: S. Piacsek) Naval Ocean Research and Developmnt Activity NSTL Station, Missisippi 39529	2
4.	Commander Naval Oceanography Command NSTL Station, Mississippi 39529	1
5.	Commanding Officer Fleet Numerical Oceanography Center Monterey, California 93940	1
6.	Officer-in-Charge Naval Environmental Prediction Research Facility Monterey, California 93940	1
7.	Librarian Naval Environmental Prediction Research Facility Monterey, California 93940	1
8.	Commander Attn: Code 8100 Attn: Code 6000 Attn: Code 3300 Naval Oceanographic Office NSTL Station Bay St. Louis, Mississippi 39522	 1 1 1
9.	Office of Naval Research Code 422 NSTL Station, Mississippi 39529	1
10.	Dean of Research, Code 012 Naval Postgraduate School Monterey, California 93940	1
11.	Prof. R.L. Elsberry, Code 63Es Naval Postgraduate School Monterey, California 93940	10
12.	Prof. R.W. Garwood, Jr., Code 68Gd Naval Postgraduate School Monterey, California 93940	1
13.	Department of Meteorology, Code 63Mm Naval Postgraduate School Monterey, California 93940	1
14.	Prof. R.L. Haney, Code 63Hy Naval Postgraduate School Monterey, California 93940	1
15.	Prof. C.N.K. Mooers, Code 68Mr Naval Postgraduate School Monterey, California 93940	1
16.	Mr. P.C. Gallacher, Code 63Ga Naval Postgraduate School Monterey, California 93940	3

17. Commanding Officer
Naval Research Laboratory
Attn: Library, Code 2627
Washington, D.C. 20375 — 1

18. Naval Research Laboratory
Code 2627
Washington, D.C. 20375 — 1

19. Deputy Under Secretary of Defense
Research and Advanced Technology
Military Assistant for Environmental Science
Room 3D120
Washington, D.C. 20301 — 1

20. NODC/NOAA
Code D781
Wisconsin Avenue, N.W.
Washington, D.C. 20235 — 1

21. Dr. J. Namias
Scripps Institution of Oceanography A-030
LaJolla, California 92093 — 1

22. Dr. Peter Niiler
Scripps Institution of Oceanography A-030
LaJolla, California 92093 — 1

23. Dr. Warren White
NORPAX A-030
Scripps Institution of Oceanography
LaJolla, California 92093 — 1